Second Series. *February, 1915* *Vol. V., No. 2*

THE

PHYSICAL REVIEW.

A DETERMINATION OF LATITUDE, AZIMUTH, AND THE LENGTH OF THE DAY INDEPENDENT OF ASTRONOMICAL OBSERVATIONS.

By Arthur H. Compton.

In a previous paper[1] an experiment was described which afforded a means of measuring the component of the earth's rotation about a vertical axis. Assuming the latitude to be known, the rate of the earth's rotation could then be calculated. The present paper shows how the same method may be employed to measure also the components of the earth's rotation about two mutually perpendicular horizontal axes, so that the rate of the earth's rotation can be determined directly. From the ratio of the vertical component to the resultant rotation the latitude may be found, and from the ratio of the two horizontal components the azimuth may be determined.[2]

If a circular tube filled with liquid is placed in a plane perpendicular to the axis about which the rotation is to be measured, one side of the tube is, in general, moving with respect to the other side. If now the tube is quickly rotated through 180 degrees about an axis in its own plane, the part of the tube on one side of the axis will have its motion changed as it is shifted to the other side, while the liquid retains a large part of its original motion. For example, if a tube bent into a ring of radius r is placed in a plane perpendicular to the earth's axis and is then turned

[1] A. H. Compton. "A Laboratory Method of Demonstrating the Earth's Rotation," Science, N. S., Vol. 37, p. 803, 1913.

[2] By experiments with an Atwoods machine, such as those conducted by John G. Hagen (John G. Hagen, "How Atwoods Machine Shows the Rotation of the Earth even Quantitatively," International Congress of Mathematics, Aug., 1912) it is theoretically possible to determine the azimuth from the ratio of the deviation of the falling weight toward the south to that toward the east. The earth-rotation ring here described, however, is the only apparatus which has been shown capable of measuring the earth's angular velocity about both vertical and horizontal axes, which is necessary for a determination of the latitude and the length of the day independent of astronomical data.

half way around about a horizontal axis, the upper portion of the tube acquires a relative velocity toward the west when turned to a position nearer the earth's axis than originally equal to $2r\omega$, where ω is the angular velocity of the earth's rotation. The liquid in this part of the tube, however, will retain its original motion, and so will have a relative momentum toward the east. Since the pivots upon which the horizontal axis rests are constrained to follow the earth in its rotation, the component of the motion of the liquid parallel to the direction of the tube at these points is without influence on the relative motion, and only that component of the liquid's momentum which is parallel to the axis will have an effect in producing relative motion when the tube is turned. So if θ is the angular distance of any small portion of the ring from the axis about which it is turned, the mean momentum per unit length of the tube which tends to cause relative motion immediately after the ring is shifted from a position perpendicular to the earth's axis through 180 degrees is:

$$\rho V = 2r\omega\rho \frac{\int_0^{2\pi} \sin^2 \theta d\theta}{\int_0^{2\pi} d\theta}$$

or

$$V = \omega r \qquad (1)$$

where ρ is the mass of the liquid per unit length of the tube, and V is the relative velocity between the liquid and the tube.

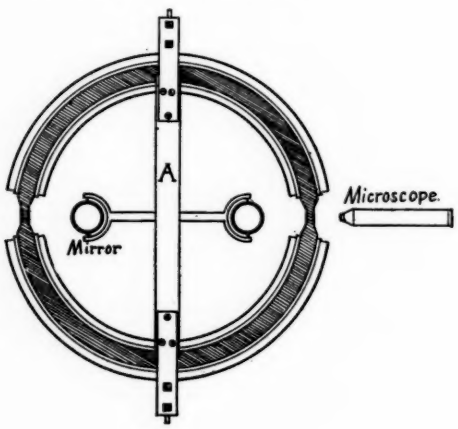

Fig. 1.

Showing the construction of the earth rotation ring.

The ring used to perform this experiment was made of one inch brass tubing bent into a circle eighteen inches in diameter. Where the windows

were placed the tube was constricted to a diameter of about three eighths of an inch, as in Fig. 1, so as to increase the velocity of the liquid at the point of observation. In order to prevent convection currents as far as possible, the tube was covered with a quarter of an inch of asbestos, and enclosed in a concentric tin tube with an intervening air space. The protected tube was then mounted on a rigid rod *A* (Fig. 1), the ends of which were made adjustable perpendicular to the plane of the ring, so that the ring might be made to swing upon an axis accurately parallel to its plane. An iron framework was so constructed that the axis could be supported in either a horizontal or a vertical position in order to measure either the vertical or the horizontal components of the earth's rotation.

Carbon disulphide was first used to fill the tube, on account of its low viscosity. Its motion was made visible by shaking up with it an aqueous solution of calcium chloride of the same density, which formed small suspended globules whose motion was easily visible through the microscope. Because of its high coefficient of expansion, however, the convection currents due to slight differences in temperature in different parts of the tube rendered the use of this liquid impracticable. In fact, no liquid could be found whose coefficient of expansion was nearly as low as that of water, so this was finally used to fill the tube. A mixture of coal oil and carbon tetrachloride was prepared of the density of water at 4° Centigrade, at which temperature most of the measurements were made. The slight change in relative density due to a rise to room temperature did not noticeably affect the motion of the smaller globules of the oil when shaken up in the water.

When the ring was held in a horizontal plane, no particular pains were required to eliminate convection currents, since the only time that a difference in density in different parts of the tube could affect the motion of the water was while it was being turned over. When the ring was held in a vertical plane, however, in order to measure the horizontal components of the earth's rotation, the slightest variation in density in different parts of the tube was immediately noticed. Great precautions were taken to keep the ring at uniform temperature throughout. The whole apparatus was enclosed in an asbestos box, and the within was stirred by an electric fan, as in Fig. 2. A further asbestos shield prevented the observer's breath from striking the enclosing box, and the surrounding air was kept well stirred by an electric fan. By this means the difference in temperature of different parts of the tube was kept within 0.05 of a degree, but even this small difference at ordinary room temperature produced convection currents comparable in magnitude

with the motion of the water due to the earth's rotation. In order to eliminate still further these currents, the apparatus was set in a constant temperature room and kept at 4° Centigrade by means of a thermostat. In this manner it was found possible to eliminate almost entirely the effect due to the convection currents.

In taking a reading, a microscope with an eye-piece scale was focused on the center of the tube under the glass window, and the ring was held in position until the oil globules had no appreciable motion. The ring was then quickly turned over, and the number of scale divisions passed by the globules between the fifth and fifteenth seconds after the ring was reversed was noted. A telegraph sounder actuated by the laboratory clock was used to measure the time during which the motion was followed. Immediately after the ring was turned over there was a large motion across the tube, but this soon died out, and the motion along the tube could be accurately measured.

TABLE I.

Reading Given in Scale Divisions.

	Case *A*.	Case *B*.	Case *C*.	Case *D*.
Setting I.	+13	+25	+10	+24
Axis vertical, Ring Approx.	+12.5	+25	+11	+24.5
ENE×WSW.	+14.8	+20.5	+13.8	+17.5
Ave. 9 r'd'gs:	+15.35	+21.19	+13.42	+19.71
X_1 = Average of 4 cases = + 17.41 divisions.				
Setting II.	− 7	−10	−14	− 8
Axis vertical, Ring approx.	− 8.2	−13	−14	− 7.5
NNW×SSE.	−10	− 9.5	− 9	− 6.5
Ave. 10 r'd'gs:	− 9.70	− 9.59	−12.33	− 6.60
X_2 = Average of 4 cases = − 9.55 divisions.				
Setting III.	+14.5	+ 8	+19.5	+17.5
Ring horizontal	+35	+20	+11	+30
	+10	+24	+32	+12
Ave. 10 r'd'gs:	+15.35	+18.20	+23.15	+17.10
X_3 = Average of 4 cases = + 18.42 divisions.				

Some typical readings thus obtained with the ring set in the three mutually perpendicular planes are shown in Table I. The four cases, *A*, *B*, *C*, *D*, represent the four different ways in which the ring may be turned. By taking the average of these four cases, differences in the readings due to slight convection currents and to inaccurate adjustment of the axis about which the ring is turned cancel out. The positive

direction is taken as upward as seen in the microscope (a real downward motion) in the first two settings, and toward the right in the third. In the first setting observations were taken on the west side of the ring, and the fact that the water was moving relatively downward on this side after the ring was reversed indicates that the earth is revolving from west to east. Similarly the relatively upward motion observed on the

$$\varphi = \text{latitude} = \sin^{-1} \frac{X_3}{\sqrt{X_1^2 + X_2^2 + X_3^2}} = 42.8°.$$

$$\psi = \text{azimuth} = \tan^{-1} \frac{X_2}{X_1} = 28.7°.$$

east side in the second setting indicates the same sort of motion. The third setting showed a relative motion to the left on the side of the ring observed, which shows a rotation of the earth in a counter-clockwise direction about a vertical axis. Thus qualitatively the rotation of the earth about the three different axes is shown.

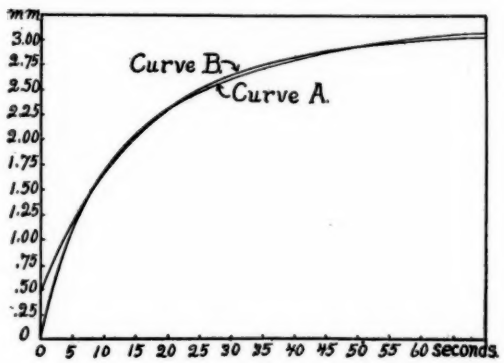

Fig. 3.

In order to make an accurate estimate of the angular velocity corresponding to any observed motion, it is necessary to find the law of motion of the water in the tube. If the motion were uniform the resistance would be proportional to the velocity, as assumed in the previous paper,[1] but this is not exactly true when the velocity changes with the time, if the motion of the water at the center of the tube be considered. For instance if the water in the tube is given an impulsive motion, immediately after the impulse the resistance at the center of the tube is zero, while the velocity is a maximum. However, if the greater part of the resistance occurs at definite points in the tube, as in the ring used in this experiment, the above law will hold more accurately than for a tube of

[1] Ibid., p. 805.

uniform diameter. An experimental test of the accuracy of this law for a uniform circular tube is afforded by a comparison of the curves A and B in Fig. 3, taken from my previous paper. Here curve A represents the motion of the water as determined by a large number of readings, while curve B represents the motion as it would be if the resistance were proportional to the velocity, showing a rather close agreement. We shall assume, therefore, that for our present purposes the resistance may be considered proportional to the velocity, that is:

$$\frac{d^2x}{dt^2} + c\frac{dx}{dt} = 0,$$

where x is the distance travelled along the tube, t is the time, and c is a constant depending upon the viscosity and density of the liquid and the dimensions of the tube. The solution of this equation may be put in the form:

$$X = \frac{V}{c}(e^{-ct_1} - e^{-ct_2}),$$

where X is the distance through which the motion of the water is followed, V is the initial velocity of the water after the ring is turned over, t_1 is the time of beginning, and t_2 that of ending the observation of the motion of the globules. Since in all the readings the times t_1 and t_2 were taken the same, the initial velocity of the water V is proportional to the distance X through which its motion is followed. But by equation (1)

$$V = \omega r,$$

so that X is proportional to ω, that is, the distance through which the water is followed is a measure of the component of the angular velocity about an axis perpendicular to the plane of the ring. Thus if we let α be the factor of proportionality,

$$\omega = \alpha X. \qquad (2)$$

Let ξ, η, and ζ be the components of the earth's angular velocity about axes perpendicular to the plane of the ring in settings I., II. and III. respectively, and X_1, X_2, X_3 be the average motions observed in the three settings. Then by equation (2)

$$\xi = \alpha X_1;\ \eta = \alpha X_2;\ \zeta = \alpha X_3.$$

If we call φ the latitude and ψ the angle between the ξ axis and the north, then from Table I.:

$$\left.\begin{aligned} \xi &= \omega \cos\varphi \cos\psi = +\ 17.41\ \alpha, \\ \eta &= \omega \cos\varphi \sin\psi = -\ 9.55\ \alpha, \\ \zeta &= \omega \sin\varphi\ \ \ \ \ \ \ = +\ 18.42\ \alpha, \end{aligned}\right\} \qquad (3)$$

from which

$$\omega = 27.08\,\alpha,$$
$$\sin\varphi = 0.680,$$
$$\varphi = 42.8^\circ = \text{latitude},$$
$$\tan\psi = 0.548,$$
$$\psi = 28.7^\circ = \text{azimuth}.$$

A quantitative determination of the absolute magnitude of the earth's angular velocity from these data may be made if the constant α in equation (2) is evaluated. An attempt was made to determine this constant by placing the ring on a spectrometer table which was turned at the desired angular velocity by means of a driving clock. The ring was turned with known angular velocity until the motion of the ring became uniform, and was then stopped under the microscope, and the motion of the water observed. The constant as determined in this way is not strictly comparable, however, with that which enters when the ring is turned over just before the motion of the water is observed. It was found necessary, therefore, to use a different method for calibrating the tube.

The method employed was a direct determination of the angular velocity of the vertical component of the earth's rotation. This was done by placing the whole apparatus upon the table of the spectrometer, as shown in Fig. 4. The table was rotated by means of the driving clock at such speed that the readings taken on reversing the ring with the clock running were approximately equal but opposite in sign to those taken when the clock was stopped. So if X_4 be the observed motion of the water when the clock was stopped and X_4' that when running, the vertical component of the earth's angular velocity is

$$\zeta = \frac{-\chi}{\left(1 - \frac{X_4'}{X_4}\right)},$$

where χ is the angular velocity at which the spectrometer table was turning. As shown in Table II., the readings for determining X_4 and X_4' were taken in alternate sets of four, one under each of the four cases, every other set being made with the clock running. In this manner all systematic errors were eliminated, so that the accuracy with which X_4 and X_4' can be determined is a direct function of the number of readings taken. It may be noted that although X_4 and X_3 are both measures of the earth's rotation about a vertical axis, the two quantities are not directly comparable, since the temperature at which X_4 was measured

TABLE II.

Apparatus on Spectrometer Table. Readings in Scale Divisions.

Case *A*.		Case *B*.		Case *C*.		Case *D*.	
Clock: Off.	On.	Off.	On.	Off.	On.	Off.	On.
+24		+37		+38		−12	
	−22		−10		−24		−63
+38		+49		+21		+16	
	−49		−22		−17		−34

Average X_4 (28 readings) = + 27.5 divisions.
Average X_4' (28 readings) = − 29.9 divisions.
χ = angular velocity of spectrometer table relative to earth
= − 3° in 512.4 sidereal seconds,
= − 0.00585 degrees/second.
ζ = vertical component of earth's angular velocity.

$$= \frac{-\chi}{\left(1 - \frac{X_4'}{X_4}\right)} = 0.673 \text{ revolutions/day.}$$

ω = earth's angular velocity.

$$= \frac{\zeta}{\sin \varphi} = 0.991 \text{ revolutions/day.}$$

was some twenty degrees higher than that for X_3, and the viscosity was correspondingly less. The quantity χ was measured directly, and was found to be − 0.00585° per sidereal second. Substituting the values of X_4 and X_4' as obtained in Table II., the vertical component of the earth's angular velocity becomes:

$$\zeta = \frac{0.00585}{\left(1 + \frac{29.9}{27.5}\right)}$$

$$= 0.00280 \text{ degrees/second,}$$

$$= 0.673 \text{ revolutions/day.}$$

But by equation (3)

$$\zeta = + 18.42\, \alpha,$$

so that

$$\alpha = 0.03656$$

and

$$\omega = 0.991 \text{ revolutions/day.}$$

The length of the day is therefore 24 hours 12 minutes in sidereal time.

These values of ω, φ and ψ may be compared with their values as determined astronomically thus:

By Data from Earth-Rotation Ring.	By Astronomical Data.	Difference.
ω = 0.991 revs/day	1.000 revs/day	0.9%
φ = 42,8°	40.4°	2.4°
ψ = 28.7°	30.1°	1.4°

The remarkable agreement of the two values of ω is only accidental, since if the true value of φ is used in determining ω by data from the earth-rotation ring,

$$\omega = \frac{\zeta}{\sin \varphi} = \frac{0.673}{0.650} = 1.034 \text{ revs./day},$$

which represents a difference of 3.4 per cent. Although the comparatively low degree of accuracy of these data renders them valueless for work which requires precision, it is interesting to find that these quantities can be determined without reference to astronomical observations.

In conclusion I wish to thank Professor Russell of the Department of Astronomy for his suggestions, and Professor Magie for his kind encouragement in carrying on this experiment.

PALMER PHYSICAL LABORATORY,
PRINCETON, N. J.
November 3, 1914.

APPLICATION OF A THEORY OF IONIZATION BY IMPACT TO THE EXPERIMENTS OF FRANCK AND HERTZ.

BY BERGEN DAVIS.

THE energy of ionization by impact of the various gases, that is, the energy required to separate an electron from a molecule, is an important constant in all theories of the discharge of electricity through gases. A number of investigators have attempted to determine the ionization voltages of the various gases, but the results obtained differ so widely among themselves that one cannot regard this constant as fixed with any degree of accuracy.

It has been shown by Professor J. S. Townsend[1] that the experimentally determined values of the ionizing impacts per cm. α at any pressure p and any electrical intensity X, could be plotted on a single curve in which the abscissæ were the values of X/p and the ordinates were α/p. That is, for all conditions, α/p is a function of X/p:

$$\frac{\alpha}{p} = f\left(\frac{X}{p}\right).$$

He[2] has recently derived an expression for this functional relation and has applied it to his experimental data for the calculation of the least voltage of ionization by impact. The values so calculated range from 23 to 29 volts. The results are not constant, and also they are greater than those obtained by other methods and also by direct experiment. This lack of constancy is probably due to the fact that his equation is not a complete expression for the relation between a, p and X.

Dr. E. S. Bishop[3] has applied to his own experimental results, a theory of ionization by impact developed by the writer,[4] and obtains the constant value of 10.2 volts as the ionization voltage of air.

However, all of these methods of determining the ionization voltage are indirect. An interesting direct method has recently been employed by Franck and Hertz.[5] There can be but little doubt that this direct

[1] Phil. Mag., Feb., 1901.
[2] Phil. Mag., Feb., 1914.
[3] PHYSICAL REVIEW, November, 1911.
[4] PHYSICAL REVIEW, January, 1907; Annal. d. Physik, Band 42, 1913.
[5] Ber. d. D. Phys. Ges., Heft 2, 1913.

method gives a more correct value of the ionization voltage than any of the indirect methods that have been employed. They have also added an interesting and fruitful idea to our conceptions of ionization by impact, namely, that in certain gases, the impacts are wholly or in part non-elastic, and in other gases the impacts are nearly or quite elastic. In general the noble gases (neon, helium) exhibit the phenomenon of elastic impact, while on the other hand, the gases that form chemical compounds readily (hydrogen, nitrogen, oxygen) behave as though the impacts were non-elastic.

The same experimenters[1] have investigated the ionization voltages for nitrogen and oxygen, with a specially designed apparatus which gives no current until the ionization voltage is reached. The current then increases rapidly with an increase of the applied voltage.

The purpose of this paper is to develop a theory of the current curves for this apparatus in the case of non-elastic impact and to compare it with the experimental results.

THEORY OF THE CURRENT CURVES.

The following assumptions are made: (*a*) The impacts are non-elastic, that is, an electron loses all of its velocity at collision with a molecule, and starts again from rest with an acceleration due to the applied electric field: (*b*) There is a certain minimum voltage ($v_0 = X\lambda_0$) below which ionization by impact can not occur: (*c*) Not every impact in which the electron has had a free run through a voltage $X\lambda_0$ results in ionization, but only a fraction of them do so. Only a small part of those ions whose paths are λ_0 result in ionization, but those that make paths $(\lambda_0 + x)$ are more effective in producing ions. The fraction of all the impacts having paths greater than $(\lambda_0 + x)$ that produce new ions is $x/(\lambda_0 + x)$, where λ_0 is the least ionizing path, and x is some path additional to λ_0. The fraction thus depends on the length of path of the ion, that is, on its energy at the moment of impact.

The derivation[2] of this fraction depends on the fundamental consideration that the effective form of a molecule is spherical, and that the *normal component* of the momentum of the ion at impact with a molecule shall be equal to or exceed a certain constant fixed value. An ion striking a glancing blow must, to be effective, possess more energy than one which strikes the molecule centrally.

The experimental arrangement used by Franck and Hertz may be schematically represented by Fig. 1, in which A is the source of the nega-

[1] Ber. d. D. Phys. Ges., Heft 2, 1913.

[2] PHYS. REV., Jan., 1907; Annal der Phys., Band 42, 1913.

tive ions, B is a wire mesh or grid, and D is a plate electrode. The ions are accelerated by the field applied at AB, and are slowed up by a reverse field applied to BD. Some of the negative ions from A pass through the grid B and cause ionization by impact in the region BD. For the sake of simplicity, it will be assumed that these ions from A derive all their energy from the field on AB, and that the field on BD is just equal and opposite to the field on AB. Those ions passing through the grid B and not making impact will just lose their velocity before reaching D, and will fall back to B. The quantity measured is the positive ionization produced in region BD by the ions that pass through B. *These* positive ions are driven to the plate D which is connected to an electrometer. Two cases will be treated separately.

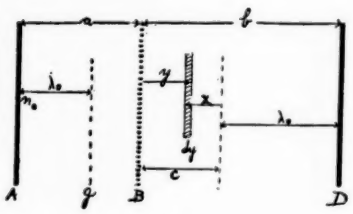

Fig. 1.

Case I.—The ionization in BD is due to the impact of the original n_0 ions starting from A.

Case II.—The ionization in BD is due to the impacts of the *new ions* produced in AB, upon *their* passage through the grid B.

Case I.—The usual laws of the kinetic theory of gases will be applied to the motion of the ions through the gas. The development becomes quite simple by reference to the figure.

Let A be the source of the n_0 ions (electrons) which acquire a velocity from the field on AB. Some of these ions pass through the grid B. The grid B will be considered a mathematical plane in the gas. The wires of the mesh have no dimensions and do not of themselves stop any of the ions. These ions have a velocity sufficient to cause ionization as they go beyond B, but if they do not make impact in a short distance, they lose their excess velocity on account of the reverse field on BD. How far they go before losing their excess energy depends on the value of the potential v applied to AB and BD.

In the figure, λ_0 is the least ionizing path, and $v_0 = X\lambda_0$ is the least ionizing voltage. The distance from A to B is denoted by a, and the distance BD by b.

The ionization by impact of which we need take account will take place in a distance C in region BD. The ionization produced in region gB need not be considered, since these positive ions cannot reach the plate D.

Let n_0 be the number of negative ions (electrons) escaping from A per unit of time. The number going beyond $(a + y)$ without impact are

$$n_0 e^{-\frac{a+y}{l}}$$

and those making impact in a space dy beyond $(a + y)$ are

$$n_0 e^{-\frac{a+y}{l}} \frac{dy}{l}.$$

Not every impact, however, produces a new ion, but a fraction of them do so. This fraction, whose derivation is referred to in a previous paragraph, is $x/(\lambda_0 + x)$.

The new ions produced in dy will be

$$n_0 e^{-\frac{a+y}{l}} \frac{x}{\lambda_0 + x} \frac{dy}{l},$$

and consequently

$$n_1 = n_0 \int_0^c e^{-\frac{a+y}{l}} \frac{c - y}{b - y} \frac{dy}{l}. \tag{1}$$

By integration, this becomes:

$$\frac{n_1}{n_0} = e^{-\frac{a}{l}} - e^{-\frac{a+c}{l}} - \frac{b - c}{l} e^{-\frac{a+b}{l}} \left\{ Ei\left(\frac{b}{l}\right) - Ei\left(\frac{b - c}{l}\right) \right\}. \tag{2}$$

An inspection of the figure shows at once that $c = b - \lambda_0$, also that $v = Xa = X'b$, and $v_0 = X\lambda_0$, where X is the electrical intensity and v is the applied voltage. The substitution of these quantities in (2) gives

$$\frac{n_1}{n_0} = e^{-\frac{a}{l}} - e^{-\frac{a}{l}\left(\frac{2v - v_0}{v}\right)} - \frac{b}{l}\frac{v_0}{v} e^{-\frac{a+b}{l}} \left\{ Ei\left(\frac{b}{l}\right) - Ei\left(\frac{b}{l}\frac{v_0}{v}\right) \right\}. \tag{3}$$

The form of the current curve is expressed in terms of the applied voltage and the dimensions of the apparatus. It will be compared to the experimental current curves obtained by Franck and Hertz. Their apparatus consisted of a hot wire source of ions (electrons) A, a cylindrical wire grid B, and a cylindrical electrode D surrounding B. The distance a was .5 cm., and distance b was 3 cm. The observations were made at a pressure of .02 mm. of Hg.

In calculating equation (3) the mean free path of a negative ion is taken at eight times the mean free path of a molecule at the pressure considered. This value, rather than the ratio $4\sqrt{2}$ was taken for the following reasons: (*a*) An expression derived by the writer[1] for the functional relation

$$\frac{\alpha}{p} = f\left(\frac{X}{p}\right)$$

is found to agree closely with all of the experimental results of Professor Townsend if one takes the mean path of an ion as about eight times that

[1] Annalen der Physik, Band 42, 1913.

of the molecule. It does not agree for any other value of the mean free path. The fundamental basis of the theory of this paper and also that employed in deriving the expression just referred to, is the same, so it is necessary to use about the same value for the mean free path of the ion in the two cases. (*b*) Recently Partzsch[1] has applied a modification of the equation of Townsend to his own investigation of the relation between the pressure, voltage and current in a gas. A good agreement is found to obtain when the mean free path of an electron is taken eight times that of a molecule.

In nitrogen at .02 mm. pressure $l = 8L$ equals 3.04 cm., and in oxygen $l = 8L$ equals 3.25 cm. at the same pressure. The values of v_0 found by Franck and Hertz were 7.5 volts for nitrogen and 9 volts for oxygen. The plotted curves for equation (3) are shown by the full lines in Fig. 2.

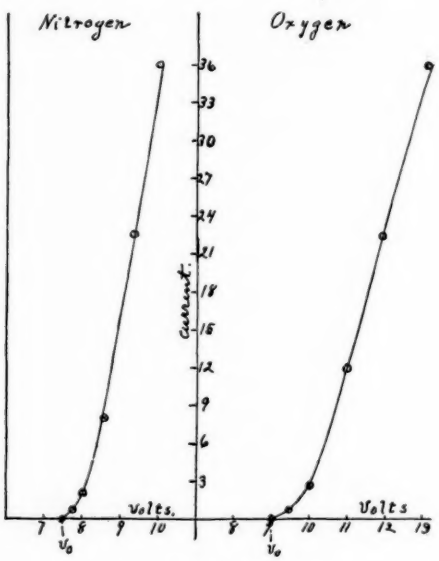

Fig. 2.

The dotted circles represent the experimental current curves obtained by Franck and Hertz.

The very good agreement here shown would indicate that the assumptions made in the development of the theory are fairly well justified, and it may be concluded that the impacts in nitrogen and oxygen are approximately non-elastic.

Case II.—The ionization in *BD* is due to the impact of the *new ions* produced in *AB* upon *their* passage through the grid *B*.

[1] Annalen der Physik, Band 40, 1913.

The total current curve will be considered as composed of two parts, n_1 and n_2. The part n_1 represents the plot of equation (3) for all values of v from v_0 to $3v_0$. It represents the ionization produced by the original ions from A. As the voltage is increased beyond $2v_0$, some of the new ions formed in region AB possess the necessary ionizing energy when they pass through B. The part n_2 represents only the ionization in BD due to these new ions from AB.

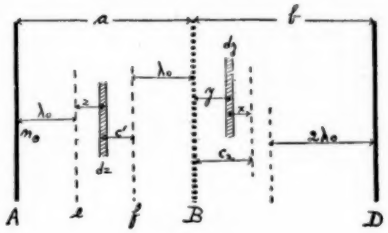

Fig. 3.

In the case of nitrogen and oxygen Franck and Hertz did not determine the current at voltages equal to or greater than $2v_0$. However, it will be interesting to investigate the form of the current curves at higher voltages, as it probably gives a method of distinguishing directly whether a gas exhibits the phenomena of elastic or non-elastic impact.

The method of deriving the equation for the current curve n_2 is similar to that of Case I. The development can be readily followed by reference to the figure.

The n_0 ions from A set free by impact new ions in the region AB. Only those that are produced in region ef, however, need be considered, since no new ions are formed in region Ae, and those ions set free in region fB have not the requisite energy on their passage through grid B. The ionization in region ef is thus a new source of ions. The extent of region ef depends on the applied voltage. When $v = 2v_0$, the planes e and f coincide. When $v = 3v_0$, the distance between the planes e and f becomes equal to λ_0.

Let dz be an element of the region ef. Some of the ions set free in dz will pass through B and cause ionization in BD as far as c_2. Their excess energy disappears beyond c_2 because of the reverse field on BD. The region dz becomes now a new source of ions whose ionizing action may be treated as in Case I.

The new ions set free in dz will be

$$dn' = n_0 e^{-\frac{\lambda_0 + z}{l}} \frac{z}{\lambda_0 + z} \frac{dz}{l}. \tag{4}$$

The same reasoning applied to these dn' ions as to the n_0 ions from A in Case I gives

$$dn_2 = dn' \int_0^{c_2} e^{-\frac{\lambda_0 + c' + y}{l}} \frac{c_2 - y}{\lambda_0 + c_2 - y} \frac{dy}{l}. \tag{5}$$

By reference to Fig. 3 it will readily be seen that

$$c_2 = \frac{b}{a}c', \quad \text{and that} \quad c' = a - 2\lambda_0 - z.$$

The complete integral equation is thus obtained

$$\frac{n_2}{n_0} = \int_0^{a-2\lambda_0} e^{-\frac{\lambda_0+z}{l}} \frac{z}{\lambda_0+z}\frac{dz}{l} \times \int_0^{\frac{b}{a}(a-2\lambda_0-z)} e^{-\frac{(a-\lambda_0-z)+y}{l}} \frac{\frac{b}{a}(a-2\lambda_0-z)-y}{\frac{b}{a}(a-2\lambda_0-z)+\lambda_0-y}\frac{dy}{l}. \tag{6}$$

The second integral term of (6) is the same as that of equation (1). It may be directly written down.

$$\frac{n_2}{n_0} = \int_0^{a-2\lambda_0} e^{\frac{\lambda_0+z}{l}} \frac{z}{\lambda_0+z}\frac{dz}{l}\left[e^{-\frac{a-\lambda_0-z}{l}} - e^{-\frac{a-b+\lambda_0\left(1+\frac{2b}{a}\right)-z\left(1+\frac{b}{a}\right)}{l}} - \frac{\lambda_0}{l}e^{-\frac{a+b-\frac{2b}{a}\lambda_0-z\left(1+\frac{b}{a}\right)}{l}}\left\{ Ei\left(\frac{\lambda_0+\frac{b}{a}(a-2\lambda_0-z)}{l}\right) - Ei\left(\frac{\lambda_0}{l}\right)\right\}\right]. \tag{7}$$

The direct integration of the variable z in the exponential integral term of (7) would be a matter of great difficulty. A graphical method of

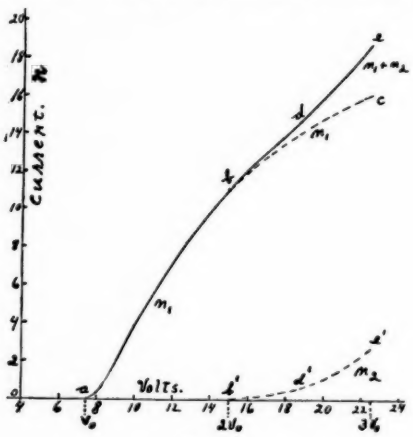

Fig. 4.

integration was used instead. Although equation (7) contains any desired dimensions (a and b) of the apparatus, for the sake of reducing

the labor of calculation somewhat, I have taken $b = a$ equal to one centimeter.

The broken line $b'd'e'$ of Fig. 4 represents the results of the graphical integration of equation (7). The curve *abc* represents equation (3) for n_1 over a voltage range from v_0 to $3v_0$. The total current indicated by the electrometer connected to D will be $n = n_1 + n_2$, and is represented by the curve *abde*.

The lack of experimental data on the form of the current curves for this design of apparatus at voltages greater than $2v_0$, prevents a complete checking of the theory. However, there is a very good agreement over that voltage range employed by Franck and Hertz. This agreement supports the assumptions made in this paper and indicates that the impacts in nitrogen and oxygen are nearly or quite non-elastic.

PHOENIX PHYSICAL LABORATORY,
COLUMBIA UNIVERSITY,
October, 1914.

A NEW FORM OF RESISTANCE THERMOMETER.

BY S. LEROY BROWN.

THE metallic oxides are generally considered to be non-conductors of an electric current. At room temperature or lower they are very poor conductors, but at higher temperatures most oxides can be considered as conductors. The resistance of powdered forms of several oxides at temperatures as high as 1100° C. has been investigated by Mr. A. A. Somerville,[1] and his results show that a specimen of copper, iron or zinc oxide may reduce its resistance from several million ohms at room temperature to a few hundred ohms at 1000° C. The determination of the resistance of a powdered specimen or a solid form which has been obtained by baking the powdered specimen, must necessarily give results which are only applicable to the particular sample under test, since much must depend on the compactness obtained in each case.

The object of this paper is to give the results of the determination of the resistance of oxides which have been melted and molded into solid rods, and to show the application of their resistance-variation with temperature as resistance thermometers.

Solid rods were obtained by filling porcelain tubes with powdered or solid forms of the oxides and melting the oxide by placing the tubes in a tubular electric furnace. By packing a porcelain tube which is 12 or 15 inches long with powdered copper oxide, melting the oxide, and allowing it to cool and harden, a solid rod can be obtained 5 or 6 inches long and 3/8 of an inch in diameter. The sample can be used encased in the porcelain, which affords some protection, or the porcelain may be ground away on an emery-wheel and the bare solid oxide obtained.

The large temperature coefficient of resistance of the metallic oxides suggested their possible value as resistance thermometers when properly made and used. The solid rods which were obtained from the molten states of some of the oxides are very hard and strong, so that their resistances are not changed by mechanical jars or small changes in pressure. The results show that a resistance thermometer can be made with a metallic oxide as the element which will withstand very rough heat treatment and any reasonable mechanical treatment, and still retain the

[1] Metallurgical and Chemical Engineering, Vol. X., No. 7, p. 422, July, 1912.

same electrical resistance at a particular temperature. Several months' use of such a thermometer with iron oxide as the element showed that many reheatings to temperatures ranging from 100° C. to 500° C. failed to cause any measurable change in its resistance.

The principal difficulty in the resistance measurements is caused by poor and variable contact resistance where the metal leads are connected to the oxide. It is impossible to solder the connecting wires to the oxides, although the solder will cling to some of them and apparently make good connections; but such connections were never found to be free from a variable contact resistance. Satisfactory connections were made by clamping two pairs of leads against the ends of the oxide element, and the potentiometer method of measuring its resistance was used. The one pair of leads carried the exciting current and the other pair were the potential leads, which were connected to the potentiometer as indicated in Fig. 1. The variable contact resistance between the oxide and the exciting-current leads is thereby eliminated if a potentiometer balance is made with the standard resistance immediately after each balance is obtained with the oxide element.

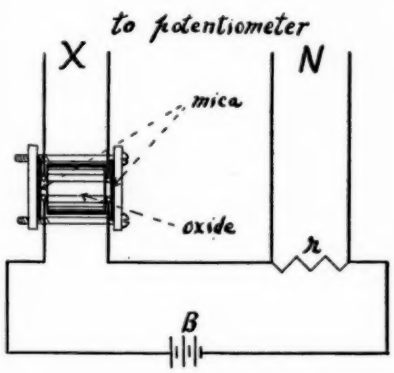

Fig. 1.

The solid copper oxide elements, with which the following data were obtained, were formed by filling a porcelain tube with cupric oxide and heating to about 1400° C. in an electric furnace. At this temperature the CuO reduces to Cu_2O. The melted cuprous oxide was withdrawn from the furnace and quickly cooled. Chemical analysis of the solid formed showed it to be about 98.7 per cent. cuprous oxide.[1] If cuprous oxide is maintained at about 800° C., it will decompose into cupric oxide and free copper. Evidently the rapid cooling accounts for the very small per cent. of cupirc oxide in these specimens. One resistance element was formed in the above described manner, then heated to 800° C. and allowed to cool slowly. The cuprous oxide decomposed into cupric oxide and free copper and the resistance of the element was reduced from about 60,000 ohms at 26° C. to about 4,100 ohms at the same temperature. A rise of temperature would decrease the resistance of the element, which then consisted of a mixture of cupric oxide and

[1] The author is indebted to Mr. D. J. Brown of the school of chemistry, The University of Texas, for the analyses of these oxides.

copper; but its resistance would be higher than originally when its temperature was reduced to the original temperature. Of course this variation in its resistance made it worthless as a resistance thermometer. This means that the upper limit of the cuprous oxide resistance thermometer is certainly under 800° C.

The solid iron oxide elements were made by filling a porcelain tube with ferric oxide, heating to about 1550° C. and then allowing to cool. The melting of the ferric oxide caused a reduction to magnetite (Fe_3O_4), and therefore the sold elements which were used as iron oxide resistance elements are solid magnetite. Chemical analysis showed the solid to be magnetite.

The solid lead oxide was obtained by melting the powdered lead oxide in an electric furnace in the same manner as described for the copper and iron oxide.

Short elements with comparatively large cross-sections can be made which have only a moderate resistance at room temperature, and small heat capacity. Iron oxide (Fe_3O_4) and cuprous oxide (Cu_2O) gave the most satisfactory results (as far as the author's investigation was extended) for temperatures ranging from a few degrees below zero to 400 or 500 degrees centigrade, although lead oxide (PbO) can be used very satisfactorily between 100 and 600 degrees centigrade. The lead oxide is more brittle than either iron or copper oxide, and therefore is easily cracked or chipped. The extremely high resistance of lead oxide at room temperatures necessitates a very thin element in order that its resistance be not prohibitive.

The accompanying data and curves show the temperature variation of resistance for the three oxides and the sensibility of an iron oxide resistance thermometer at several temperatures. The sensibility at a particular temperature is expressed as the change in resistance per degree per unit of resistance at the particular temperature; that is, the sensibility at a particular temperature is the slope of the temperature-resistance curve at that temperature, divided by the resistance at that temperature. The sensibility of these thermometers is very much higher at low temperatures, but they are sufficiently sensitive at high temperatures to warrant their use.

OXIDE RESISTANCE THERMOMETER NO. 1.

Description.—The resistance element of this thermometer consists of a cylindrical piece of cuprous oxide (Cu_2O) encased in a porcelain tube in which cupric oxide had been melted. The length of the element is .6 of a centimeter and its diameter is .8 of a centimeter.

The resistance measurements for all the data in this paper were made with a Wolff potentiometer, and connections were made to the oxide as shown in Fig. 1. For all temperatures up to 200° C., the resistance

TABLE I.

Temperature.	Resistance.	Temperature.	Resistance.
− 3.2° C.....	83,750	96° C.....	4,943
.2 "	71,600	117.5 "	3,820
.6 "	70,250	130.1 "	3,220
1.9 "	66,750	146 "	2,610
8.4 "	49,650	162 "	2,043
16 "	36,100	185 "	1,521
27.3 "	23,500	198 "	1,285
28.5 "	22,550	221 "	1,012
34.2 "	17,000	251 "	770
45 "	12,200	281.5 "	615
58 "	8,515	327 "	438
81 "	5,920	375 "	319.2

thermometer was placed in a uniformly heated oil bath and the temperatures measured with a standardized mercurial thermometer. The higher temperatures were obtained by a tubular electric furnace and measured with a standardized platinum, platinum-iridium thermo-couple.

The heavy curves in Fig. 2 show the resistance variation with tem-

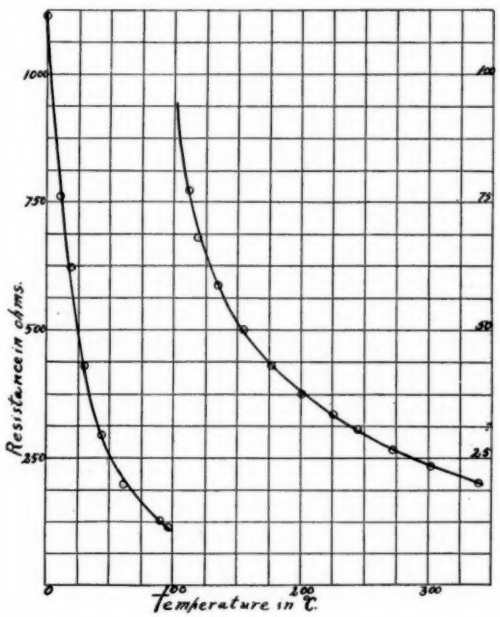

Fig. 2.

perature for cuprous oxide. The scale on the right margin refers to the curve which pertains to temperatures higher than 100° C.

OXIDE RESISTANCE THERMOMETER NO. 2.

Description.—The element of this thermometer is similar to the element of No. 1 except it is 9.35 centimeters long.

TABLE II.

Temperature.	Resistance.	Temperature.	Resistance.
0° C.	8,915,000	29.42° C.	2,678,300
1 "	8,490,000	30.22 "	2,610,000
2.5 "	7,840,000	30.92 "	2,560,900
9 "	6,452,000	34.2 "	2,090,000
17.5 "	4,448,000	45 "	1,498,000
22 "	3,585,000	58 "	1,048,000
27.2 "	2,922,000	75 "	749,000
28.5 "	2,772,000	89.8 "	568,000

The dotted curve in Fig. 2 shows a graph of the above data if the scale at the left margin is multiplied by 100.

OXIDE RESISTANCE THERMOMETER NO. 3.

Description.—The element of this thermometer consists of a solid piece of lead oxide (PbO) which is .7 of a centimeter long and about .75 of a centimeter in diameter. The cross-section is not quite uniform.

TABLE III.

Temperature.	Resistance.	Temperature.	Resistance.
52° C.	4,285,000	116° C.	124,900
60 "	3,535,000	120 "	102,600
68 "	2,760,000	136 "	57,800
76 "	1,998,000	149 "	37,800
81 "	1,510,000	168 "	23,550
91 "	762,500	184 "	12,510
94 "	466,000	202.5 "	6,175
97.7 "	368,500	230 "	3,711
110 "	191,000	259 "	1,468

The curves in Fig. 3 show the resistance variation with temperature for lead oxide. The scale at the right margin refers to the curve which pertains to temperatures higher than 100° C.

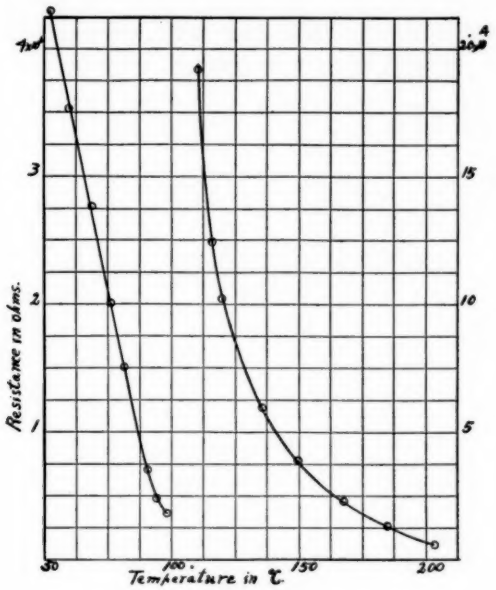

Fig. 3.

OXIDE THERMOMETER NO. 4.

Description.—The resistance element of this thermometer consists of a cylindrical piece of solid magnetite (Fe_3O_4) which was obtained by melting powdered iron oxide (Fe_2O_3). The length of this element is .85 of a centimeter and its diameter is .65 of a centimeter.

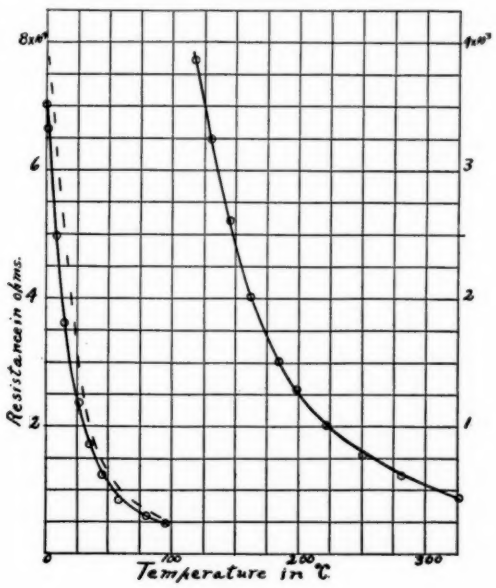

Fig. 4.

TABLE IV.

Temperature.	Resistance.	$S=1/R \cdot dR/dt$.	Δt
−3° C.	1 377		
−1.2	1,202		
0	1,116.01	.061	±.0033
.06	1,111.90		
.13	1,107.29		
.80	1,065.90		
1.1	1,049.61		
10	762.8		
11.2	745.9		
16.2	635.5		
19.51	570.81		
20.00	562.501	.030	±.0067
20.47	554.79		
20.81	549.21		
21.2	542.9		
22	520.5		
22.4	524.4		
23.1	514.3		
24.05	500.59		
25.00	487.92	.027	±.0074
26.12	473.58		
27.9	452.0		
28.9	440.0		
29.45	434.82		
30.00	428.94	.025	±.0080
30.33	425.42		

Temperature.	Resistance.	$S=1/R \cdot dR/dt$	Δt
44.1	295.7		
62.3	195.2		
90	125.5		
96.60	113.75		
97.13	112.81		
98.86	109.83		
99.82	108.21	.015	±.013
112.5	77.2		
120.6	67.8		
135.4	58.3		
155.4	50.0	.010	±.018 estimated from curve.
177.7	43.3		
201.5	37.6	.007	±.028 estimated from curve.
226.5	33.4		
245	30.5		
249	29.9	.0055	±.036 estimated from curve.
272	26.7		
302	23.5	.0047	±.042 estimated from curve.
340	20.3		
352	19.5	.0042	±.048 estimated from curve.
365	18.5		

In Table IV., S = sensibility of the thermometer No. 4 expressed in ohms change in resistance per degree centigrade per ohm. Δt = error involved in measuring a small change of temperature at the respective temperatures, assuming that the resistance can be measured with an error not greater than .01 of one per cent.

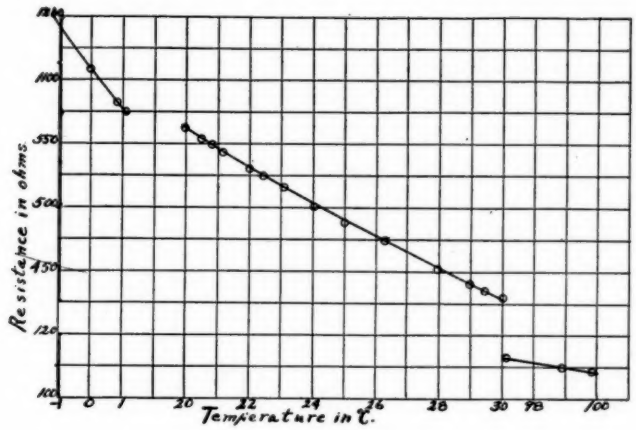

Fig. 5.

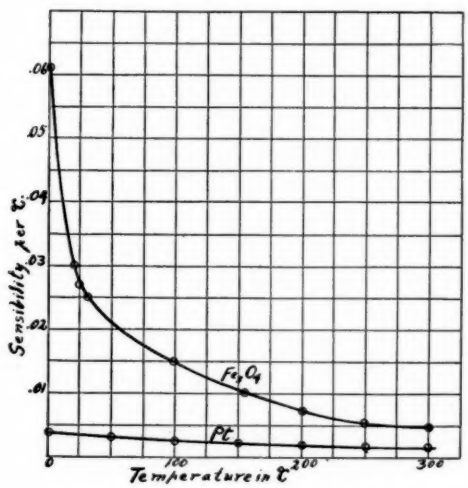

Fig. 6.

The temperature readings which are carried to the second decimal place were taken with a Beckmann thermometer.

Fig. 4 shows the variation of resistance of the magnetite with temperature.

Fig. 5 shows the resistance variation of thermometer No. 4 on an

enlarged scale at room temperature, near zero, and near 100° C. The resistance of the magnetite between 10° C. and 30° C. can be expressed in terms of the resistance at 20° C. by

$$R_t = R_{20}(1.82 - .0524t + .00057t^2)$$

with an error of less than .2 of one per cent., where t is the temperature of the oxide in degrees centigrade. If the resistance of an iron oxide thermometer is accurately determined at a known temperature which is near 20° C., an unknown temperature which is greater than 10° C. and less than 30° C. can be determined by the aid of the above parabolic equation with an error of less than .1° C.

The sensibility of a magnetite thermometer and of the platinum resistance thermometer are shown graphically in Fig. 6. A comparison of the two curves shows that the magnetite thermometer is about 16 times as sensitive as the platinum thermometer at ice temperature, and about 8 times as sensitive at room temperatures.

PHYSICAL LABORATORIES,
THE UNIVERSITY OF TEXAS.

THE DIURNAL VARIATION OF THE EARTH'S PENETRATING RADIATION AT MANILA, PHILIPPINE ISLANDS.

BY LEOPOLD J. LASSALLE.

RUTHERFORD and Cooke[1] first called attention to the presence of a penetrating γ radiation, which they attributed to the presence of radio-active substances in the earth's surface. McLennan and Burton,[2] independently reported the discovery of a similar phenomenon. C. T. R. Wilson[3] had previously shown that the so-called "spontaneous ionization" of air in a closed vessel, which enabled it to conduct electricity, was also present when other gases were used; and that, further, the relative values of the ionization for these gases were approximately in the same ratio as those found for the same gases when acted upon by Becquerel rays. J. Paterson[4] called attention to the fact that the value of the ionization, when large vessels were used, was not proportional to the pressure, but tended towards a limit beyond which the ionization value was not increased by further increase of pressure. This pointed to the ionization being due to a feeble radio-activity of the walls of the vessel, the α rays from which were totally absorbed—under given conditions of size of vessel, of nature of gas, and of radio-activity of walls of vessel—for a given pressure. Since the relative values of the ionizations caused by α, β, and γ rays are, respectively, 10,000, 100, and 1, it is seen that the more easily absorbed α rays will practically determine the ionization in a vessel, the inside surface of which is radio-active. In order to test further this theory, Strutt,[5] used cylinders of the same dimensions but of different materials, and found the values for given pressures to vary with the material. Also, for different samples of the same material he found the ionization to vary. In the matter of reaching a maximum at a certain pressure, his results were in agreement with those of J. Paterson. Using one sample of tin-foil the maximum ionization was obtained at 29.8 inches pressure. For another sample of tin-foil the maximum was found at a pressure of 24.5 inches. This

[1] Rutherford and Cooke, Amer. Phys. Soc., Dec., 1902.
[2] McLennan and Burton, PHYS. REV., 16, p. 184, 1903.
[3] C. T. R. Wilson, Proc. Roy. Soc., Vol. LXIX.
[4] J. Paterson, Proc. Camb. Phil. Soc., Vol. XII.
[5] R. J. Strutt, Nature, Vol. 67, p. 369, 1902.

investigator concluded that the ionization in a closed vessel was not spontaneous at all, but was due to the Becquerel rays from the walls of the ionizing vessel; and that radio-activity, instead of being rare, was everywhere present. It should be noted, in criticism of this conclusion, that the finding of different values for the radio-activity of different samples of the same material points to the activity being due to the presence of some of the rare radio-active substances as impurities in the metals of which the walls of the ionizing vessels were made, rather than to it being due to an inherent property of these metals. In order to reach some basis of comparison a crystal of uranium nitrate, having an exposed area equal to 48 sq. cm. was cemented inside of the cylinders. The rate of leak was then found to be thirteen times as great as when the most active sample of platinum was used for the ionizing chamber. The area of platinum exposed was 240 times that of the crystal. Therefore we may conclude that the uranium nitrate was about 3,000 times as active as the sample of platinum. Radium is about 100,000 times as active as uranium nitrate. So, the conclusion is reached that one part of radium to 300,000,000 parts of platinum would be sufficient to account for the observed activity. Prof. Armstrong,[1] in criticising this attempt to explain the nature of the ionization as being due to a radio-activity of the walls of the chambers, suggests that it might be due to some chemical change, such as oxidation. In answer, Strutt[2] makes the following clear-cut and concise statement, which undoubtedly furnished a basis for much of the later work on this very important subject:

"Prof. Armstrong suggests that the effect observed by myself and McClennan may be due to chemical change or to oxidation at the surface instead of to radio-activity. In speaking of the radio-activity of various metals, I mean that they exhibit effects differing only in degree from those shown by uranium and radium. These effects, observed experimentally, are as follows: (1) There is a leakage of electricity from a charged body in their neighborhood, the value of the leak being proportional to the E.M.F. for small E.M.F.s, and independent of it for large ones. (2) The effect varies with the pressure of the air in the chamber; being proportional to the pressure for small pressures; and, for large ones, independent of it, when E.M.F. is sufficient. (3) The rate of leak for positive electricity is the same as that for negative electricity. (4) The rate of leak does not depend upon the temperature. (5) When other gases are substituted for air the rate of leak is nearly proportional to the density of the gas, excepting for hydrogen, which

[1] Prof. Armstrong, Nature, Vol. 67, p. 414, 1903.

[2] R. J. Strutt, Nature, Vol. 67, p. 439, 1903.

gives about one eighth the effect that air does. Every one of these points gives exact agreement between uranium and ordinary materials. On the other hand, I am not aware that any differences have been brought to light, except in magnitude of effect. Until such a difference should appear I think we may fairly and without dogmatism apply the maxim that similar effects are due to similar causes. In other words, we may conclude that the other substances, like uranium, are radio-active."

It was at about this time that Rutherford and Cooke, as previously mentioned, called attention to the result of experiments from which they concluded that a part, at least, of the ionization caused in a closed chamber was due to a penetrating radiation having its origin outside the chamber. They were able to reduce the ionization 30 per cent. by surrounding the chamber with lead sheets 3 cm. thick. A pig casting of lead, weighing 5 tons, and very much thicker than 3 cm., did not reduce the ionization any further. Surrounding the chamber with a considerable thickness of water reduced the ionization. Surrounding the instrument with wood or with brick increased the ionization, showing that these substances were radio-active or that a secondary activity was excited at their surfaces. Metals exposed outside the building for some time showed a marked increase in radio-activity over that which such metals had after having been carefully cleaned.

McLennan and Burton,[1] at about the same time reached the conclusion that, since they had been able to reduce the ionization in a closed vessel by 37 per cent., any explanation as to the cause of the ionization must take into account this penetrating radiation here shown to exist.

N. R. Campbell,[2] from a long series of observations which are very prettily analyzed, reaches the following conclusions:

(1) The influence which the walls of a containing vessel are known to exert upon the spontaneous ionization of the enclosed air, may be attributed to radiations proceeding from the walls. (2) That part of the radiation emanating from such substances as tin, zinc, graphite, and platinum is analogous to the secondary radiations excited by Röntgen and other such rays, being caused by the penetrating radiation which Cooke cut off with thick lead screens. (3) The coefficient of absorption of air for this radiation is comparable with that of air for α rays from radium. (4) The coefficient of absorption is different for different materials; and, therefore, it is improbable that the radiation is due to radio-active impurities. It is more probably due to an inherent property

[1] McLennan and Burton, Phil. Mag., p. 699, Vol. 5, 1903.

[2] Norman R. Campbell, Phil. Mag., p. 531, Vol. 9, Ser. 6, 1905.

of the material. (5) That there is no evidence of the existence of rays, from ordinary materials, more penetrating than the α rays from radio-active elements. Finally, it is obviously of great importance to determine the nature of the rays from ordinary materials, their charge, their velocity, etc. The problem, however, will tax the ingenuity of the ablest experimenters.

This same line of investigation was continued by Alexander Wood.[1] He concluded that the ionization in a closed vessel was due, 1st to a penetrating radiation; 2d, to a secondary radiation caused by the penetrating radiation; and, 3d, to an intrinsic radiation from the walls of the vessel that is independent of the penetrating radiation. Some further results which he obtained are not pertinent to the matter in hand and so will not be considered here.

In a paper in 1905, A. S. Eve[2] concluded: (1) That the radium required to maintain a steady supply of emanation to the amount found per cubic kilometer of air near the earth is between 0.14 and 0.49 gm. (2) This amount of emanation and its successive products is sufficient to cause ions to be produced at the rate of 9.6 per c.c. per second. (3) The radium emanation in the air is probably sufficient to account wholly for the natural ionization in large closed vessels of non-radio-active materials, and for the rate of production of ions near the earth. However, in a paper in 1908, Eve[2] concludes, among other things, that the value of 4.5 ions per c.c. per second in a closed brass vessel as found by H. L. Cooke[3] cannot be attributed to the active matter in the atmosphere but that the radium present in the earth's crust is about of the right order of magnitude to account for it.

Wood and Campbell[4] concluded that there was a double diurnal variation in the ionization in a closed vessel, which appeared to be connected with the potential gradient changes in the atmosphere.

Wright, in Toronto, did not find such a diurnal variation.

G. A. Cline,[6] from a rather extended series of observations at Toronto, failed to detect a diurnal variation. He found that the penetrating radiation was greater after a fall of the barometer and smaller after a rise; the radiation was smaller when the ground was frozen and covered with snow than when it was bare and the temperature above freezing. The foregoing was for an open chamber. With a closed one he also

[1] Alexander Wood, Phil. Mag., p. 550, Vol. 9, Ser. 6, 1905.
[2] A. S. Eve, Phil. Mag., p. 98, Vol. 10, Ser. 6, 1905.
[3] A. S. Eve, Phil. Mag., p. 189, Vol. 12, 1908.
[4] H. L. Cooke, Phil. Mag., p. 403, Vol. 6, Ser. 6, 1903.
[5] Wood and Campbell, Phil. Mag., p. 265, Vol. 13, 1907.
[6] G. A. Cline, PHYS. REV., p. 35, Vol. 30, 1910.

failed to find any regular diurnal variation, although there was a larger variation in the values at different times than when the open chamber was used. Different metals used for the chamber showed different activities; that for zinc being very low. The general conclusion was reached that the soil furnished by far the greater portion of the penetrating radiation present at the earth's surface at Toronto; and by comparison any that may have its source in the atmosphere or in the sun may be considered negligible in amount.

Ideal Method of Attacking Problem.—It has been pointed out a number of times that to be able to draw conclusions regarding the ultimate cause or causes of the radio-activity on the earth, it is necessary that a number of closely related phenomena be investigated at the same place, at about the same time, and by investigators working under the direction of one person. That the time and place should be the same is made necessary by the effect of geographical position, of climatic conditions, and of altitude upon the various radio-active constants the determination of which is to throw light upon the larger question of the radio-activity on the earth. The investigation should be conducted under one head so that it can be uniform and comparable; otherwise it is impossible to draw reliable conclusions from the rather disconnected data obtained. In short, there should be a cohesiveness, rather than an adhesiveness to hold together the various parts and make it one problem. There are four main heads under which the parts of this problem have been classified: (1) The determination of the radium content of the atmosphere. (2) The investigation of the nature and amount of active deposit on a negatively charged wire. (3) The qualitative and quantitative investigation of the penetrating radiation at the earth's surface. This investigation will give the necessary data to show whether there is a diurnal variation for the locality investigated. And (4) The determination of the value of the ionization of the atmosphere. There are two other closely related subjects that should be studied in connection with this problem. They may be classified as branches of the fourth main head above mentioned. They are: Potential gradient in the atmosphere, and nucleation of the ions in the atmosphere. It was under the inspiration of such an ideal scheme that Dr. J. R. Wright, professor of physics in the University of the Philippines, Manila, P. I., who was investigating the first of these four problems, started three members of his department on the three remaining problems. Due to the slowness with which it is possible to obtain apparatus at Manila, it was found necessary to deviate from the program. The result is that the first problem was thoroughly investigated, the report appearing

in a paper by J. R. Wright and O. F. Smith.[1] The second problem was investigated by Mr. Blackwood, but no report of it has appeared to date. It was the intention of Wright and Smith to investigate the fourth problem. This paper is the report of the work done on the third problem.

Description of Instrument Used.—The instrument with which this investigation was carried on was a Spindler and Hoyer, aluminium-leaf electroscope, which had an ionization chamber 7.8 cm. inner diameter and a volume of 1850 c.c. A rod one mm. in diameter was connected to the leaf system of the electroscope, and was in the center of the ionization chamber. The electrical capacity of the chamber plus that of the electroscope was 8.6 E.S. units. The leaf could be read to tenths of a division, with a probable error of + or − two tenths. Fig. 1 is a photograph of the instrument. The larger of the three cylinders was used, throughout the observations, as the ionizing chamber.

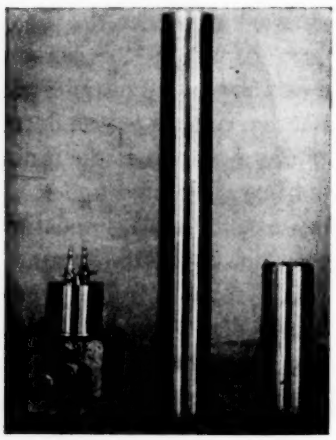

Fig. 1.

Procedure.—The procedure adopted was to seal off the ionization chamber, to connect one of the stop-cocks to an oil vacuum-pump, and the second to a drying tube and to a tube of cocoanut carbon, the two tubes being connected in series. The second stop-cock was closed and the chamber was exhausted to a vacuum of about two or three cm. Air was then slowly allowed to enter through the cocoanut carbon and drying tubes. In this way the chamber was filled with air that was dry and practically emanation free. Both stop-cocks were then closed and disconnected from everything outside. The chamber was not absolutely air-tight, but so long as the difference in pressure between the inside and the outside was small, there was very little tendency for air to leak out or in. The range of the one hundred scale divisions was from 346 down to 268 volts, assuring saturation voltages. To begin with the electroscope was simply charged and the deflection of the leaf for several hours observed.

Formula.—From the formula

$$N = \frac{C \cdot \Delta E}{V \cdot t \cdot e}, \qquad (1)$$

the value of N, which is the number of ions per c.c. per second formed in

[1] Wright and Smith, The Philippine Journal of Science, Vol. 9, No. 1, Sec. A, Feb., 1914.

the chamber, was determined. The source of the radiation that caused the ionization in the chamber may have been in the earth's crust, in its atmosphere, or in some source external to the earth. Also, it may have been resident in the material of which the chamber was made, either as an inherent property of such material or as a result of contamination with some radio-active substance. Any leak over the insulation, which would have to be corrected for, if present, was guarded against by carefully cleaning the amber insulation with absolute alcohol and by drying the air that was allowed to enter the chamber. An open vial of concentrated sulphuric acid placed inside the electroscope proper kept the air therein dry.

It is evident that the charge necessary to cause the voltage of an insulated system, of capacity C, to drop by an amount ΔE, is given by

$$Q = C \cdot \Delta E. \tag{2}$$

Also, if N ions are formed per c.c. per second within the ionization chamber of volume V, for t seconds, and if each ion carries a charge of e E.S. units, then

$$Q = NVte. \tag{3}$$

Eliminating Q from (2) and (3), there results

$$N = \frac{C \cdot \Delta E}{V \cdot t \cdot e},$$

which is (1). The value of 4.77×10^{-10} E.S. units, as obtained by R. A. Millikan, was used for e. C and V were known, and t and ΔE are the variables that were observed.

Preliminary Results. It soon became evident that the value of N varied within wide limits, depending upon the time at which the observations were taken. This led to preliminary sets of readings, taken as follows: The electroscope was charged and allowed to stand about an hour before the first reading was taken. From this time on, for the next thirty-six hours, each scale reading and the time at which it occurred were recorded. The next twelve hours were taken up in resting. A period of about a week was spent in this way. Since the time of the scale readings did not fall on the hours or the half hours, it was necessary to interpolate to find what the readings were at each hour. Then, the change in scale reading per hour, reduced to E.S. units of P.D., gave the ΔE for one hour, *i. e.*, for $t = 3{,}600$ seconds. From (1) the value of N for each of the twenty-four hours of the day was calculated. This was done for each day and then the mean of N for each hour was obtained.

TABLE I.

Date.	12:00 M.	1:00 A. M.	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00 A. M.	12:00 N.
5–18–13	....	....	....	....	....	....	....	....	....	....	....	....	....
5–19–13	1.14	1.28	1.14	1.07	1.06	1.07	1.13	0.80	0.73	0.73	0.71	0.72	0.99
5–20–13	....	....	....	1.03	1.14	1.21	0.91	0.69	1.01	0.51	0.62	1.62	1.00
5–21–13	1.52	1.21	1.13	1.15	1.13	1.17	1.02	0.86	0.87	0.55	0.57	0.59	0.65
5–22–13	....	....	....	....	....	....	....	....	....	....	1.40	1.41	0.83
5–23–13	0.81	1.58	1.22	1.13	1.13	1.17	0.99	0.94	0.65	0.73	0.81	0.82	0.90
5–24–13	....	....	....	....	....	....	....	....	....	....	....	....	1.50
5–25–13	1.26	0.87	1.49	1.14	1.44	1.22	1.23	1.13	0.61	0.46	0.79	0.91	0.83
5–26–13	....	....	....	....	....	....	....	....	....	0.62	0.63	1.23	1.24
5–27–13	0.91	1.00	1.06	1.24	1.03	0.96	1.05	0.97	1.22	0.93	0.66	0.70	1.37
5–28–13	....	....	....	....	....	....	....	....	....	0.57	0.66	0.89	...
5–29–13	1.39	1.08	1.01	1.08	1.13	1.18	1.29	0.68	0.93	0.72	0.59	1.09	0.49
5–30–13	....	....	....	....	....	....	....	....	....	....	....	....	....
5–31–13	1.05	1.35	1.40	1.28	1.25	1.22	1.01	0.85	0.84	0.51	0.42	0.71	1.02
6– 1–13	....	....	....	....	....	....	....	0.64	0.63	0.64	0.78	0.80	0.90
6– 2–13	1.10	1.03	1.11	1.30	1.28	1.36	1.24	0.81	0.72	0.77	0.92	0.87	0.83
6– 3–13	....	....	....	....	....	....	....	....	....	....	....	0.75	0.69
6– 4–13	1.35	1.24	1.14	1.02	1.17	1.11	1.21	0.68	0.68	0.69	0.66	0.75	0.80
6– 5–13	....	....	....	....	....	....	....	....	....	....	....	....	....
6– 6–13	1.39	1.25	1.24	1.00	0.94	0.95	1.13	0.96	1.15	0.89	0.62	0.50	0.74
6– 7–13	....	....	....	....	....	....	....	....	....	0.79	0.68	0.69	0.74
6– 8–13	1.00	1.18	1.27	1.10	1.15	1.06	1.30	0.87	0.76	....	....	0.65	0.72
6– 9–13	....	....	....	....	....	....	....	....	....	....	0.63	0.72	0.87
6–10–13	1.15	1.24	1.23	0.96	0.96	1.11	1.28	1.12	0.70	0.48	0.65	0.75	0.62
6–11–13	....	....	....	....	....	....	....	....	....	....	....	0.58	0.57
6–12–13	1.01	1.18	1.22	1.17	1.18	1.36	1.15	1.11	0.97	0.39	0.85	0.51	0.80
6–13–13	....	....	....	....	....	....	....	....	....	....	0.97	1.42	0.75
6–14–13	....	....	....	....	....	....	0.96	0.97	0.90	0.58	0.47	0.71	....
6–15–13	1.04	1.12	1.08	1.07	1.01	1.02	1.02	1.50	0.94	0.72	0.71	0.89	0.87
6–16–13	....	....	....	....	....	....	....	....	....	0.59	0.49	....	....
6–17–13	....	....	....	1.16	1.00	1.11	1.19	1.07	0.86	1.08	0.63	0.68	0.77
6–18–13	....	....	....	....	....	....	....	....	....	....	....	....	....
6–19–13	....	....	1.07	1.07	1.08	1.05	1.00	0.98	0.91	0.92	0.70	0.65	0.66
6–20–13	....	....	....	....	....	....	....	....	1.20	1.61	0.40	0.41	0.60
6–21–13	....	....	....	....	....	1.06	1.06	1.17	0.85	0.83	0.84	0.84	0.83
6–22–13	1.03	....	....	....	....	....	....	....	....	....	....	....	....
Mean divs. per hour.....	1.143	1.186	1.187	1.116	1.122	1.134	1.114	0.940	0.862	0.720	0.700	0.829	0.843
Mean ions per c.c. per second.....	8.06	8.35	8.36	7.87	7.92	8.00	7.85	7.63	6.08	5.08	4.94	5.81	5.95

TABLE I.

1:00 P. M.	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00 P. M.	Average for the Day.	Weather Conditions.
....	....	....	....	....	....	....	1.43	1.19	0.83	1.29	1.19	Fair
1.11	0.69	1.07	1.37	1.20	1.22	1.23	1.40	1.00	....	....	1.04	"
0.82	1.16	1.56	1.15	0.93	1.12	1.14	1.29	1.31	1.01	0.76	1.05	"
0.75	1.12	1.14	1.03	1.04	1.03	1.55	1.07	....	....	....	1.01	"
0.92	1.11	1.31	1.06	1.62	2.22	1.39	1.12	1.04	1.32	1.28	1.29	"
1.29	1.12	0.92	1.13	1.07	0.96	1.13	1.32	....	....	....	1.04	"
1.25	0.49	0.63	1.00	1.54	1.65	1.63	0.66	1.38	1.46	1.39	1.22	"
0.95	1.88	0.66	1.04	0.94	1.32	1.61	....	....	....	....	1.09	"
0.78	1.26	1.98	1.60	0.93	0.93	1.24	1.32	0.99	0.83	1.19	1.12	Light Rain
1.27	1.19	1.15	0.96	0.98	1.13	1.20	1.20	....	....	....	1.06	" "
....	....	....	....	2.39	1.38	1.56	....	....	....	....	1.24	Fair
0.55	0.44	1.05	1.65	1.09	0.98	1.22	1.62	0.94	....	....	1.01	"
....	....	....	1.28	1.19	1.62	1.43	1.13	1.21	1.17	1.32	1.33	"
1.23	1.25	0.93	1.02	1.14	1.06	1.32	1.74	....	....	....	1.08	"
1.02	0.91	0.87	....	....	1.34	1.59	1.43	1.53	1.09	1.18	1.02	"
0.96	1.22	0.96	1.27	1.40	1.30	1.24	1.09	0.27	....	....	1.05	"
1.15	1.15	0.94	1.14	0.96	1.05	1.48	1.44	1.26	1.11	1.04	1.09	"
0.79	1.14	1.37	2.26	1.25	0.74	....	....	....	....	....	1.05	"
....	....	....	....	....	....	1.25	1.28	1.24	1.17	1.26	1.24	Heavy rain
0.74	0.58	1.21	1.97	0.63	0.98	1.21	1.01	....	....	....	1.00	Fair
0.79	1.01	1.01	1.26	....	....	....	....	1.03	1.20	1.01	0.93	"
0.86	0.81	1.03	1.33	1.12	0.88	1.26	1.12	0.85	....	....	1.08	"
0.74	0.97	1.56	1.38	1.24	1.09	1.06	1.17	1.08	1.06	1.03	1.04	"
0.86	1.42	....	....	....	1.42	1.22	....	....	....	....	1.01	Rain
0.57	1.02	0.93	1.06	1.08	0.86	1.13	1.36	1.18	1.21	1.18	0.98	Fair
0.74	0.78	1.05	1.60	0.35	1.48	0.86	1.31	1.67	....	....	1.04	Heavy rain
0.88	0.93	1.30	1.32	....	....	....	....	1.03	1.05	....	1.07	Fair
....	0.85	0.89	1.40	1.36	1.39	1.05	1.08	1.17	1.18	1.18	1.01	"
0.79	0.84	1.02	1.20	1.12	1.05	1.11	0.99	....	....	....	1.01	"
....	....	1.23	1.02	1.29	1.21	1.71	1.33	....	....	....	1.11	"
0.77	1.09	0.99	1.28	1.19	1.01	0.92	1.03	....	....	....	0.99	Heavy rain
....	0.73	1.02	1.33	1.26	1.07	1.02	1.08	....	....	....	1.07	" "
0.79	1.08	1.16	....	....	1.10	1.43	1.11	0.97	1.06	....	0.99	" "
0.72	0.77	1.26	1.21	1.13	1.16	1.00	0.98	1.45	1.22	0.94	1.01	Fair
0.75	0.97	1.03	0.97	1.21	1.06	1.02	1.23	....	....	....	0.99	"
....	1.34	1.10	0.88	0.90	0.94	0.86	0.86	0.98	....	....	0.99	"
0.884	0.976	1.111	1.272	1.158	1.180	1.252	1.208	1.129	1.123	1.146	1.055	
6.26	6.88	7.81	8.96	8.15	8.31	8.82	8.50	7.95	7.90	8.06	7.43	

These N's were plotted against times as shown in Fig. 2. While the curve is rather irregular, there certainly is a decided minimum at 11 A. M. and a decided maximum at 4 P. M. The mean N for the minimum at 11 A. M. is 5.2, and that for the maximum at 4 P. M. is 11.5. The maximum is, therefore, more than twice the minimum. The mean is practically the same whether it be obtained by averaging all the 24 values for the different hours of the day, or by averaging only the maximum and the minimum. The former method gives 8.05 for mean N, and the latter gives 8.35.

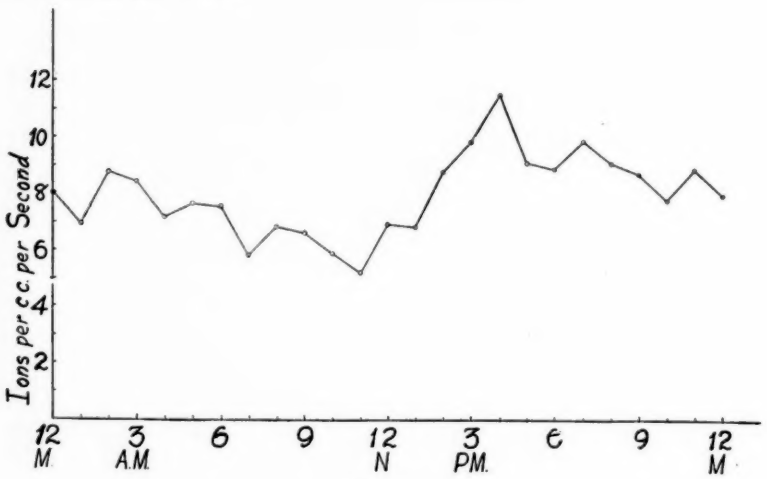

Fig. 2.

Final Results.—This preliminary test seemed conclusive in establishing the fact that there was a true diurnal variation in the value of the penetrating radiation at Manila. But it was felt that a longer series of observations was needed to determine more accurately the time of the maximum and of the minimum as well as their value and the value of the mean. With this object in view, the electroscope and ionization chamber were set up in a stone bungalow, the residence of the author, at 217 Valenzuela, Santa Mesa, Manila, P. I. This was considered a desirable location as it was far from any possible source of radio-active matter, such as might be present in the neighborhood of a physical or chemical laboratory. It was also at one of the highest spots in Manila, and the air had free access from all directions. Another important consideration, since readings extended over 36-hour periods, was that rest could be obtained between readings. Thanks are due to Mrs. L. J. Lassalle who frequently made the observations from five to ten A. M. Had it not been for this aid, it would not have been possible to observe 36 hours out of each 48, as was done.

Final Series Shows a Diurnal Variation.—Table I. is a complete record of the calculations for N obtained from the data taken during the period extending from May 18, 1913, to June 22, 1913. The calculations consisted of interpolations so as to get the scale readings at each half hour. Then, the difference between the readings for one mid-hour and the next gave the change in scale-readings per hour. It is evident that this difference is proportional to ΔE. Since C V, t, and e are constant for a given instrument, this difference is proportional to N, the number of ions per c.c. per second formed in the ionization chamber. In this case $N = 7.05 \times$ divisions per hour. In Fig. 3, N is plotted

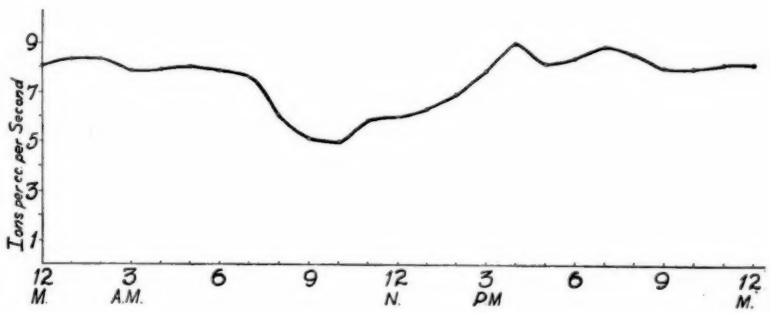

Fig. 3.

against time. The curve shows a decided minimum at 10 A. M. equal to 4.94 and a decided maximum at 4 P. M. equal to 8.96, the maximum being nearly twice the minimum. The mean obtained by averaging all 24 values is about 7 per cent. higher than that obtained by averaging the minimum and the maximum. The minimum N is practically 5 and the maximum is practically 9. *These observations seem to establish the fact beyond a doubt, that there is a true and decided diurnal variation in the value of the ionization in a closed vessel at Manila, P. I.* It would be very interesting to have observations of this nature extended over a whole year, so as to see whether or not the nature of the variation would change with changing seasons. These observations are for the end of the dry season, just before the beginning of the wet or typhoon season.

Further Deductions from the Data Obtained.—The results obtained do more than show a diurnal variation; they throw some light on the nature of the cause or causes of the ionization in a closed vessel. The possible causes are:

1. Radio-active gases in the vessel, but having their origin outside of it;
2. Radio-active impurities in the material constituting the vessel;
3. An inherent radio-activity of the material constituting the vessel;

4. A penetrating radiation from the radio-active matter known to be in the earth's crust;

5. A penetrating radiation from the radio-active matter known to be in the earth's atmosphere;

6. A penetrating radiation from the sun or other non-terrestrial sources. In addition, a leak over the insulation of the leaf system would cause a deflection of the leaf that would be supposed to be due to an ionization in the vessel. Therefore, we may classify as

7. A leak over the insulating system of the leaf.

The effect of (1) was practically eliminated by allowing the vessel to remain closed for about two weeks before the observations were taken. Radium emanation has a half-period value of 3.85 days; and in 15 days its activity will decay to about 7 per cent. of its original value. Also, the air allowed to flow into the tube, after it had been exhausted to a vacuum of about 3 or 4 cm., was passed over cocoanut carbon in a long tube, thus robbing it of almost all the emanation in the first place. Thorium emanation has a half-period value of 53 seconds, while for actinium emanation the value is 3.9 seconds. It is evident that even if some of these gases did enter at first, their activity would have decayed to practically nothing in two weeks.

It may be that either or both of 2 and 3 produce the ionization in the vessel. However, their effect in the present instance must have been small, for after sealing off the tube in the manner previously mentioned the mean value of N for each of several successive days was calculated. There was no indication of a gradual rise in the value of N, as would necessarily have been the case had there been any radio-active materials, either as impurities or otherwise, in contact with the air within the vessel. Also, there could hardly be any explanation of the diurnal variation in the value of the ionization having its origin in either 2 or 3. The only theory that it would be reasonable to advance would be that a temperature variation might cause the emanation from the inner walls of the vessel to be given off more rapidly when the temperature is high than when it is low. However, the temperature at Manila during fair weather is appreciably constant from 10 A. M, to 4 P. M.; and it is between these hours that N varies from its minimum to its maximum. It is therefore, reasonable to conclude that the effect of 2 and 3 is small in this particular vessel.

If radio-active matter in the sun furnished any appreciable cause of the ionization, one would expect the minimum to occur at night. However, there might be a lagging of the effect after the cause is removed. Even then it would be expected that the variation would give a more

symmetrical curve than the one obtained. That is it would be reasonable to expect the period of highest value and that of lowest value to each extend over twelve hours, even though the former did not fall during the day and the latter during the night. The best evidence that the sun is not a factor is furnished by the work of Simpson[1] at Karasjoh in Norway, which shows that the active matter deposited on a negatively charged wire is about the same in amount in summer, as in winter when the sun does not rise above the horizon. Other non-terrestrial sources are so numerous that it would not be advisable to try to consider them here. Suffice it to say that it seems improbable that any other source, not on the earth, would be as likely to be the source of the ionization as would be the sun.

A leak over the insulation was guarded against by drying the air that entered the vessel and by freeing it from dust particles. It was also observed that, when the vessel was exhausted the leaf did not appreciably deflect for several hours. We may, therefore, say that the effect of 7 was very small.

Thus we have 4 and 5 left as the main causes of the ionization in the closed vessel. One cannot offer any explanation of a possible diurnal variation in the amount of radio-active matter in the soil in Manila. Since we assume the effect of all other causes excepting 4 and 5 to be small, and since the effect of 4 is assumed steady during the time over which these observations extend, the conclusion is forced upon us that the diurnal variation is a variation in the value of the penetrating radiation from the earth's atmosphere. Since N varies from 5 to 9, it is also evident that the effect of the active matter in the atmosphere is responsible at times for at least 4 ions per c.c. per second at Manila. The cause of the diurnal variation is probably that the air which sweeps over this locality at certain times has been over water for a long enough period of time to have lost some of its activity by decay. At other times the air comes from over the land, so that it is in radio-active equilibrium with the active matter in the earth's crust. That is, whatever activity it is gaining is equal to that which it is losing by decay. At a given season of the year there is a steady recurrence of sea and land breezes at Manila; so that it is to be expected that there will be a steady recurrence of the maximum and of the minimum for the ionization in a vessel if this ionization is due at all to the active matter in the atmosphere. In addition to the shifting of the air from land to sea and vice versa, due to temperature changes, there is generally another motion of the air, called a typhoon. There may also be vertical air currents. Since the

[1] Simpson, Phil. Trans. Roy. Soc., *A*, 205, p. 61, 1905.

data to determine these three components is not at hand it is impossible to determine exactly the direction of the resultant at any time. While it would be rather difficult to determine these factors, they are necessary to a complete solution of the problem in hand. It is not to be expected that such a variation will be found at points where there are no considerable bodies of water near, over which the air might remain long enough to lose a considerable part of its activity.

It was thought possible that the value of N might be connected with the kind of weather which prevailed while the observations were being taken. Most of the five weeks were fair, but there was one period at the beginning of the fifth week when there were heavy rains for three days. There were two or three other days when there were heavy rains. The mean of N for all periods following heavy rains is 7.16 while the mean for the remaining time is 7.72. It is to be expected that following heavy rains the pores of the earth will be filled so that the radio-active gases will not be able to escape so readily. However, the data at hand from which to draw conclusions regarding this matter is rather limited as the difference is very small for clear and for rainy weather. The time to get data on this point is during the rainy season.

SUMMARY.

1. A diurnal variation in the value of N, the number of ions per c.c. per second formed in a closed vessel in Manila, was found, The maximum of 8.96 occurs at 4 P. M., and the minimum of 4.94, at 10 A. M. The mean for N is found to be 7.43.

2. It seems probable that the main causes of the ionization are the radio-active materials in the soil and the radio-active matter in the atmosphere.

3. Since there is no reason to suppose that the former of these two causes might have a diurnal variation, it must be that this variation is in the latter cause.

4. The air currents at Manila have a diurnal variation, sea breezes blowing at times and land breezes at other times. While the exact nature of the relationship cannot be established from the data available, it seems probable that the minimum must occur at a time when the air over the land is air that has blown from over the sea where it has previously remained long enough to lose a considerable portion of its activity by decay. The maximum, which is fairly steady from 3 P. M. to 6 A. M., must be due to the air which is over land during this period having previously been mainly over land for some considerable time.

STATE COLLEGE, PA.

AN ADDITION TO A THEORY OF IONIZATION BY IMPACT.

BY H. W. FARWELL.

SOME time ago Bergen Davis[1] developed a theory of ionization by impact which has been very suggestive and of particular interest in the consideration of non-elastic impacts. The experiments of Franck and Hertz[2] have shown that in certain gases, such as oxygen, nitrogen, and hydrogen, the impacts are practically all of this character, so that this assumption in Davis's theory is not without support in experiment. The lack of accord between this theory and some of the experimental evidence is due to the fact that the impacts in all cases were originally considered to be non-elastic. In confining attention now to those gases in which the impacts have been shown to be of this kind, there is still cause for differences between fact and theory.

The original paper assumed that there were present in the space ionized all possible ionic paths between zero and infinity, whereas of necessity many of the experiments have been carried out with relatively small distances between the plates of the condenser. It is hardly necessary to point out that under such conditions the average number of ionizing impacts per centimeter can not be determined with accuracy, and differences between theory and results of such experiments may be held against the experiment rather than against the theory.

It seemed worth while to extend the theory to cover all such cases, though the method of calculating the number of ionizing impacts may still cause small differences. Following Davis's reasoning exactly the number of ionizing impacts which an ion makes in traversing a distance dx just beyond a path $\lambda_0 + x$, where λ_0 is the shortest path along which the necessary energy for ionization can be acquired, is given by

$$\frac{1}{l}\epsilon^{-\frac{\lambda_0 + x}{l}}\frac{x}{\lambda_0 + x}\frac{dx}{l},$$

where l is the mean free path of the ion. If now the ion is in a field due to a condenser whose plates are a distance D apart, the quantity x may have any values between 0 and $D - \lambda_0$. The complete expression

[1] PHYS. REV., XXIV., p. 93, Jan., 1907. Also Ann. d. Phys., 42, p. 807, 1913.

[2] Ber. d. Deuts. Phy. Ges., 15, p. 613, 1913. Also p. 929, 1913.

for the number of ionizing impacts per centimeter is then

$$\alpha = \frac{1}{l}\int_0^{D-\lambda_0} \epsilon^{-\frac{\lambda_0 + x}{l}} \frac{x}{\lambda_0 + x}\frac{dx}{l}.$$

This expression is, like the original, not integrable in finite terms, but can be integrated in a form involving the exponential integral.[1]

The solution is

$$\alpha = \frac{1}{l}\left\{\left[\epsilon^{-\frac{\lambda_0}{l}} + \frac{\lambda_0}{l} Ei\left(-\frac{\lambda_0}{l}\right)\right] - \left[\epsilon^{-\frac{D}{l}} + \frac{\lambda_0}{l} Ei\left(-\frac{D}{l}\right)\right]\right\}$$

where Ei ( ) denotes the exponential integral. This is Davis's solution with a correction term added, and reduces to his solution when the distance between the plates is large.

The magnitude of the correction term can be computed for any given conditions, but to avoid tedious calculation the curves below have been

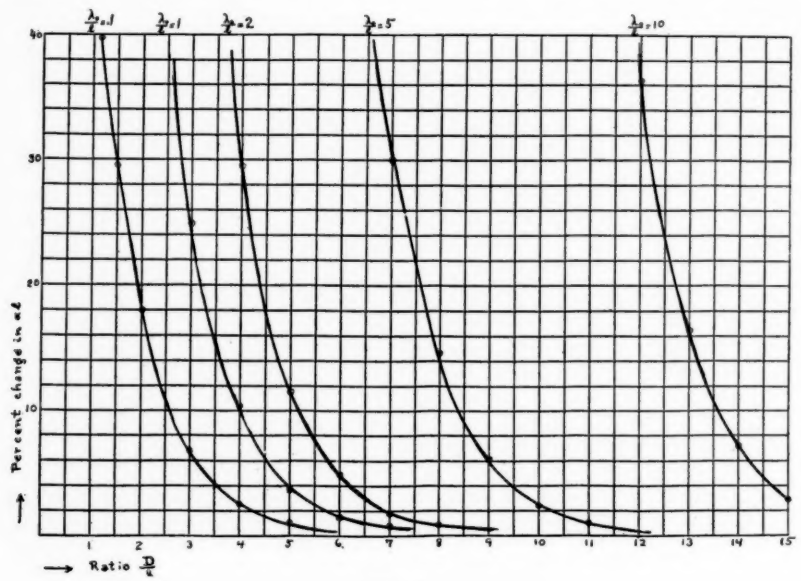

Fig. 1.

plotted to represent the amount of this correction under various conditions. The abscissæ give the ratio of plate-distance to ionic mean free path, and the ordinates give the magnitude of the quantity $\epsilon^{-\frac{D}{l}} + (\lambda_0/l)\, Ei(-D/l)$ expressed in per cent. of the quantity αl, or in other words the ordinates give the per cent. error in determining α for a given pressure. The curves have been plotted only for the range of values likely to occur

[1] Bierens de Haan, Verh. Kon. Ak. Wet., Vol. II., 1854, p. 214.

in observations of the current between parallel plates, and give at once the error if the observer has a measure of D and l. Curves of this sort may be used to determine the lower limit for plate distance in experimental work. Without mentioning the specific instances it may be remarked that there are numerous cases where experimenters have taken observations with plates separated by such a small distance as to lead to errors in α of fairly large magnitude.

Partzsch[1] has made a similar addition to Townsend's expression for the current

$$n = n_0 \epsilon^{\alpha D}$$

since this expression would indicate an increase in the current even though the applied voltage was less than the ionizing voltage. Expressed in symbols already used, Partzsch's modification may be written

$$n = n_0 \epsilon^{\alpha D\left(1-\frac{\lambda_0}{D}\right)} = n_0 \epsilon^{\alpha(D-\lambda_0)}.$$

This, like Townsend's, gives from the experimental results the values of α, but the reasoning from it to deduce the ionizing voltage would be open to the same objections as those made by Franck and Hertz[2] to the original form.

This addition to Davis's formula is in itself of minor importance, but it may serve to aid further inquiry into the process of ionization by impact and the character of electron paths.

PHŒNIX PHYSICAL LABORATORY,
COLUMBIA UNIVERSITY,
October 15, 1914.

[1] Verh. Deutsch. Phys. Gesell., 14, p. 60, 1912.
[2] Ber. Deutsch. Phys. Gesell., Jan. 15, 1914.

ATOMIC NUMBERS AND ATOMIC CHARGES.

BY FERNANDO SANFORD.

IN a paper entitled "Untersuchungen ueber das System der Grundstoffe" (Lund, 1913), Rydberg has undertaken to show that the properties of the elements which determine their positions in the periodic series may be calculated from the number which represents the order of their occurrence in this series. Thus he says:[1]

"In the system of Mendelejeff all the elements are arranged in a single series, and each element is distinguished from all others by its place in this series. This signifies that *a single independent variable suffices to completely determine each element.* According as a quantity to be determined varies continuously or discontinuously must the independent variable pass through the continuously increasing series of all numbers or the discontinuous series of the positive whole numbers. In the case before us one cannot doubt that the properties of the elements vary discontinuously from element to element. Continuous variation in the properties of the elements may, indeed, occur, but only in consequence of a continuous change in temperature, pressure, and the like, of the same element. Between the individual elements there is no continuous transition.

"We are accordingly led to the adoption of the series of the positive whole numbers as the independent variable for the system of the atoms."

Rydberg then undertakes to show that the characteristics of the atoms upon which the periodic law was based may be calculated by means of the mathematical relations between their atomic numbers. He does not propose any physical explanation of these numerical relations.

Such a physical relation is suggested in a discussion by A. van den Broek, entitled Die Radioelemente, das periodische System und die Konstitution der Atome.[2] van den Broek concludes from the change in atomic weight of the elements produced by radioactive changes that, in general, the atomic weight changes from atom to atom in the periodic series by about two units, and that the deviations from this law are accidental.[3] He also assumes that each change in atomic weight is

[1] Translation by present writer.

[2] Phys. Zeitsch., XIV., 32 (1913).

[3] See article by present writer in Jour. Am. Chem. Soc., XXXIII., 1349 (August, 1911) and Theo. Wulf, Phys. Zeitsch., XII., 497 (1911).

accompanied by the gain or loss of a definite electrical charge, hence the positive sub-atom or nucleus of an elementary atom should carry a charge proportional to the serial number of the atom in the chemical series. This hypothesis gives a physical significance to the atomic numbers which Rydberg regards as the descriptive characteristics of the elements.

Previous to this Rutherford[1] and Barkla[2] had concluded from the scattering of α-particles and of X-rays that the elementary atom carries a positive charge which is proportional to half its atomic weight. van den Broek concludes that the atomic number should be substituted for half the atomic weight in the above hypothesis.

In the recent work which has been done upon the spectra of the X-rays given off by various elements when these are bombarded by cathode rays it has been found that in its high frequency radiation as in its visible radiation each element has a characteristic spectrum. The work of the Braggs, of Mosely and Darwin and, more recently, of Mosely has shown that the X-ray spectra of the different elements are very similar; that they are, in general, characterized by five lines of much greater intensity than the rest of the spectrum, and that corresponding lines in the spectra of different elements may be identified. When the relative frequencies of these lines are determined by reflection from the same analyzing crystal, it has been found that this vibration frequency is greater the higher the atomic weight of the element.

In his paper in Phil. Mag., XXVII., 703 (1914), Mosely has extended his measurements on X-ray frequencies to include all the elements from aluminium to gold, and has related the frequencies of corresponding lines in different spectra to the serial numbers of the respective atoms in Mendelejeff's table. He concludes that the vibration frequency of the line α (α being the line of lowest frequency in the X-ray line spectra of the elements) varies as the quantity $(N - k)^2$, where k is a constant and N is the serial number of the element, aluminium being taken as 13.

Mosely then concludes from a discussion of Rutherford's theory of atomic structure that the change in frequency of the vibrating electrons which produce this line must be due to a change in the magnitude of the positive charge on the nucleus of the atom. He states his conclusions as follows:

1. Every element from aluminium to gold is characterized by an integer N which determines its X-ray spectrum. Every detail in the spectrum of an element can therefore be predicted from the spectra of its neighbors.

[1] Phil. Mag., XXI., 669 (1911).
[2] Ibid., XXI., 648 (1911).

2. This integer N, the atomic number of the element, is identified with the number of positive units of electricity contained in the atomic nucleus.

3. The atomic numbers for all the elements from Al to Au have been tabulated on the assumption that N for Al is 13.

4. The order of the atomic numbers is the same as that of the atomic weights, except where the latter disagrees with the order of the chemical properties.

5. Known elements correspond with all the numbers between 13 and 79 except three. There are here three possible elements still undiscovered.

6. The frequency of any line in the X-ray spectrum is approximately proportional to $A(N - b)^2$, where A and b are constants.

Mosely does not give a table of frequencies of the same line for all the elements he has examined, but on page 709 of his paper he gives curves showing both the wave-length and the square root of the frequency of many of these lines plotted against the atomic numbers. These curves are very approximately straight lines. It accordingly seems that whether the charge of the positive nucleus of an atom is, or is not, proportional to the atomic number, N, the frequencies of the principal lines of the X-ray spectra are proportional to the squares of these atomic numbers.

The present writer has published several papers in this journal and in others, beginning in 1911,[1] in which it has been shown that the product of the atomic weight of an element multiplied by the migration velocity of its ion in the electrolysis of dilute water solutions gives a number which has been shown to be related to all the properties of elements and their compounds which depend upon affinity or cohesion, as well as to many optical properties and to the dielectric constants of several of the elements. It may accordingly be worth while to compare the atomic constants calculated in this way with the atomic charges which van den Broek and Mosely infer from the atomic numbers.

Since the ionic mobilities given by different investigators differ by considerable quantities, I have used in this comparison only the elements and the ionic velocities given in Kaye and Laby's Tables. Mobilities are there given for twenty elements. These elements with their atomic numbers as given by Rydberg,[2] and their atomic charges as calculated by me, assuming the charge on the hydrogen ion as 5, are given in the table below.

[1] PHYS. REV., XXXII., 512 and 518; XXXV., 276; N. S., I., 211 and 446. Astrophys. Jour., XXXV., 1; XXXVI., 255.

[2] Since Rydberg introduces two hypothetical numbers between hydrogen and helium, Mosely's atomic numbers are each two less than the number for the same atom as given by Rydberg. This will make no difference in the curves plotted for the present article.

TABLE I.

Element.	*N*	Chg.	Element.	*N*	Chg.
H.....	1	5	Br.....	37	84.9
Li.....	5	3.6	Rb.....	39	91.2
F.....	11	14.6	Sr.....	40	71.5
Na.....	13	15.7	Ag.....	49	91.6
Mg.....	14	17.3	Cd.....	50	83.8
Cl.....	19	36.5	I.....	55	132.5
K.....	21	39.6	Cs.....	57	142
Ca.....	22	32.5	Ba.....	58	119.4
Cu.....	31	46.7	Tl.....	83	212
Zn.....	32	47.6	Pb.....	84	199.4

It will be seen from the above table that while the atomic charges increase as the atomic numbers increase they do not increase at the same rate for the univalent and divalent ions. This has been shown elsewhere

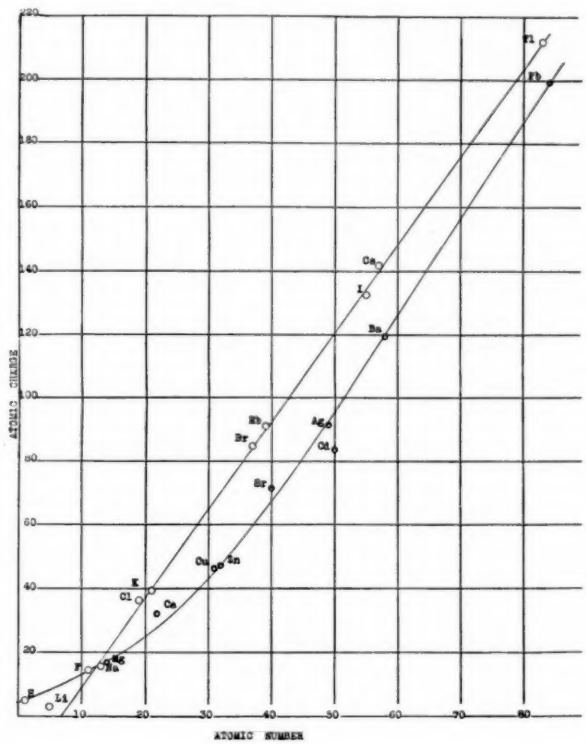

Fig. 1.

for all the other properties which seem to depend upon the atomic charges. The relation of these two sets of charges to the atomic numbers are shown graphically by the two curves in Fig. 1.

It will be seen from these curves that a straight line relation exists between the atomic charges of the univalent ions and their corresponding atomic numbers, and hence that these charges may be accurately calculated from the atomic numbers. This does not seem to be so generally true of the divalent elements, though these, with the exception of cadmium, lie on a smooth curve which does not differ much from a straight line for the elements heavier than calcium. The case of cadmium does not necessarily furnish an exception, since it is known that cadmium salts are usually made up of complex molecules which ionize by successive steps, so that in solutions of finite concentration both ions usually contain cadmium. This makes the determination of the transference number for cadmium very difficult, if not impossible, and would regularly make it appear too low, as is indicated by its atomic charge.

Since the frequencies of corresponding lines in the X-ray spectra of the elements may be calculated from the atomic numbers, it follows that for the monovalent elements, at least, they may be calculated from the atomic charges determined in electrolysis.[1] It does not necessarily follow, however, that the charges of the ions determined in electrolysis are the same as the charges of the positive atomic nuclei in the Rutherford atom. In fact, they cannot be the same, since the charges calculated for the halogen ions in electrolysis are electronegative.

The distinction between the properties of the electropositive and electronegative atoms has been shown in many ways by the present writer, though it is now seen that the magnitude of both kinds of charges may be calculated from the atomic numbers. Thus, while all the properties depending upon cohesion have been shown to be quantitatively related to the atomic charges, the magnitude of cohesion increases with the increase of the negative atomic charge but decreases with the increase of the positive atomic charge. This relation, which has been shown in previous papers, may also be exhibited by plotting the magnitude of such properties as compressibility, melting point, boiling point, critical temperature, hardness, and the like, against the atomic numbers of the elements. Thus, Fig. 2 shows graphically the relation of the melting points of the alkali metals and of the electronegative halogen elements to their respective atomic numbers. I have previously shown that the melting points of the alkali metals may be calculated

[1] In this connection it may be mentioned that in Astrophysical Journal, XXXVI., 255 (Oct., 1912), the present writer has shown that the convergence frequencies in the spectral series of a number of elements may be calculated from their atomic charges. It follows that these may also be calculated from the atomic numbers, and that the frequencies of the visible spectra as well as the X-ray spectra may be shown to be related through the atomic numbers or atomic charges.

from their atomic charges as accurately as they can be measured. They may also be calculated to a high degree of approximation from the equation $(N + 3)(T - 275) = 1{,}497$, where N is Rydberg's atomic number and T is the melting point, absolute.

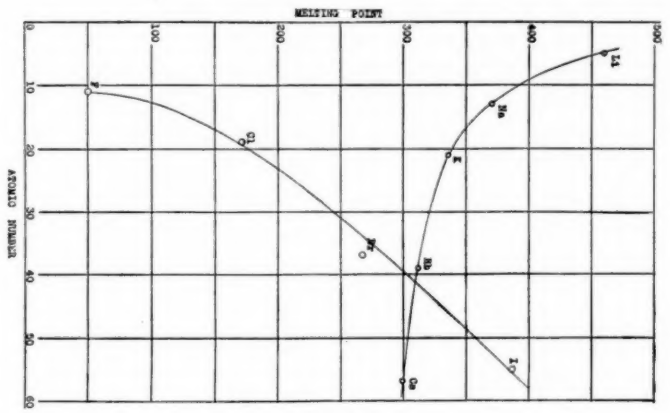

Fig. 2.

A similar relation between atomic numbers and melting points may be shown for many closely related groups of elements, but while within a given group the melting point is higher the more electronegative the

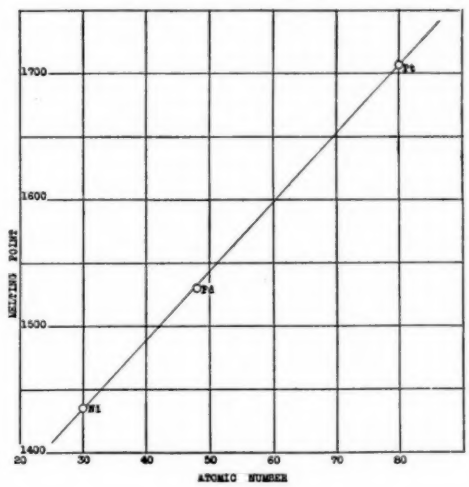

Fig. 3.

element, the melting point may either increase or decrease with the atomic number, as is shown in Fig. 2. Examples of the increase of melting point with the increase of the atomic number in metals may be shown

in the three similar groups, iron, ruthenium, osmium; nickel, palladium, platinum; cobalt, rhodium, irridium. This relation for nickel, palladium and platinum is shown graphically in Fig. 3. The melting points used are those given in Kaye and Laby's Tables. Within each set of triplets from which the above elements are taken, on the contrary, the melting point decreases as the atomic number increases.

The above considerations make it seem to the writer that while the electrical properties of the elementary atoms are in some manner closely related to their respective serial numbers, it is not probable that these numbers represent in all cases the magnitudes of the electropositive charges of the sub-atoms.

STANFORD UNIVERSITY,
October 3, 1914.

TEMPERATURE CHANGES ACCOMPANYING THE ADIABATIC COMPRESSION OF STEEL.

BY K. T. COMPTON AND D. B. WEBSTER.

INTRODUCTION.

THE formulæ of Clapeyron, which apply to reversible transformations of a body whose state is a function of two independent variables, lead to the conclusion that all substances which expand when heated will experience a rise in temperature when mechanically compressed, and vice versa. It was first shown by Lord Kelvin[1] that, as a result of the second law of thermodynamics, the rise in temperature $\Delta\theta$ produced in a rod or wire by an increase ΔF in the stretching force should be expressed by the equation

$$\Delta\theta = -\frac{a\theta}{\pi r^2 \rho s J}\Delta F,$$

where r and ρ are the radius and density, respectively, of the wire, a is its thermal coefficient of expansion, s is its specific heat, θ is the absolute temperature and J is the mechanical equivalent of heat.

Joule[2] first attempted a verification of this equation by measuring the temperature changes produced by suddenly stretching or compressing various liquids, metals, wood, rubber, etc. Although in a general way Joule's observations agree with the theory, there is an average discrepancy between theory and experiment amounting to about 15 per cent.

Later Edlund,[3] experimenting with metal wires, showed that the *relative* temperature changes in different metals may be accurately predicted by Thomson's formula, but failed to prove the *absolute* accuracy of the formula. In the case of steel, for instance, the apparent temperature increase was only 63 per cent. of that predicted by the formula.

By using a greatly improved method of measuring small temperature changes in wires and by taking into account the effect of possible variations in the thermal coefficient of expansion of the wire at different tensions,[4] Haga[5] succeeded in verifying Thomson's formula within 2.54

[1] Edinb. Trans., 20, p. 283, 1883; Winkelmann, Handbuch der Physik, 2, Vol. 3, p. 637.
[2] Proc. Roy. Soc., 8, p. 353, 1857; Phil. Trans., 149, p. 91, 1859.
[3] Pogg. Ann., 126, p. 539, 1865.
[4] Dahlander, Pogg. Ann., 145, p. 147, 1872; Winkelmann, Hand. d. Phys., 2, Vol. 3, p. 60.
[5] Ann. d. Phys. u. Chem., 15, p. 1, 1882; Winkelmann, Hand. d. Phys., 2, Vol. 3, p. 637.

per cent. in the case of steel and within 0.25 per cent. in the case of german silver for changes of 21.715 and 17.134 kg. respectively in the stretching force.

Each of these investigators measured the change in the temperature of the wire by means of a thermocouple of which one junction was soldered to the stretched part of the wire and the other to an unstretched portion of the same wire. The disagreement in the results of investigations of this phenomenon are largely due to the difficulties involved in accurately measuring the small temperature changes. These changes are small, amounting to about 0.5° C. in the case of steel suddenly stretched to its elastic limit. But the quantity of heat liberated or absorbed is very small, owing to the small heat capacity of the metal wire, and this heat is so rapidly lost by surface conduction and radiation from the wire that the galvanometer, with its period of swing of several seconds, is unable to register the total initial change in temperature.

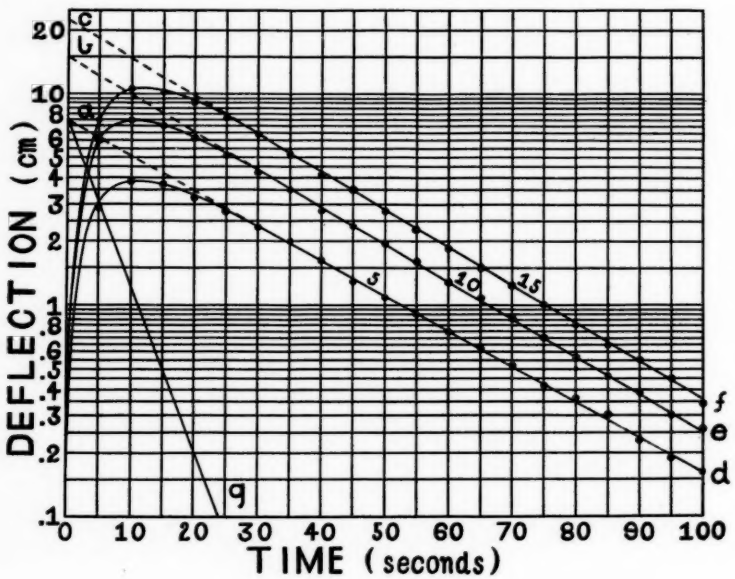

Fig. 1.

Haga employed a Thomson galvanometer whose period of swing was 6 seconds and whose damping factor was less than the critical value, so that it possessed an oscillatory swing. From the equation of motion of the galvanometer and observations of the first three swings following a change in the tension of the wire, he was able to calculate the deflection which would have been observed instantaneously after changing the tension if the inertia of the moving system of the galvanometer had

been zero. To this was added an approximate correction for the deflection produced during the time (2 seconds) required to make the change in the tension. From the deflection thus calculated, the sensitiveness of the galvanometer, the resistance of the circuit and the constants of the thermocouple the initial change in the temperature of the wire could be calculated.

In the present investigation we discarded the thermocouple method of measuring the temperature change and employed a resistance method. The stretched wire formed one arm of a Wheatstone's bridge and the temperature change was calculated from the change in the resistance of the wire accompanying the removal of the stretching force. There are several features of this method which commend it as preferable to the thermocouple method. In the first place it is far more sensitive. A calculation of the current through the galvanometer when the bridge is thrown out of adjustment by a slight change in the temperature of the wire compared with the current which would be produced through the galvanometer by the same temperature change in an iron-platinum thermocouple shows that the resistance method may be made several hundred times more sensitive than the thermocouple method. In our apparatus the sensitiveness was about thirty-five times that of Haga's apparatus. In the second place the resistance method is free from possible errors due to the Peltier effect, which is a disturbing factor in all thermocouple work except that in which a balanced or potentiometer method can be employed. The Peltier effect would be of especial significance in this work, since the supply of heat near the junction is so minute. Such an error would tend to decrease the apparent temperature change, and is therefore in a direction to account for the fact that practically all the temperature changes observed by investigators have been smaller than those predicted by the theory. Finally, by using a strongly damped galvanometer, the computations were greatly simplified and instead of rather complicated calculations the results may be obtained graphically, as is shown later in the paper. The resistance method, however, can be employed only in the case of metals and then only for stretching forces so far within the elastic limit that there is no elastic lag. For this reason we chose steel piano wire as the material for investigation, and carefully tested it with a micrometer microscope to prove the absence of appreciable elastic lag within the region of the stretching forces which we employed.

Method.—One end of a steel piano wire was soldered into a heavy lug which was held rigidly in a clamp, while the other end was passed over a pulley and was attached to a constant weight of 2.5 kg. which main-

tained a taut horizontal length of 160 cm. of wire between the lug and the pulley. About 10 cm. from the pulley a short piece of No. 10 copper wire was soldered to the steel wire and dipped into a mercury cup. The lug and the mercury cup were the terminals of the 150 cm. length of wire which formed one arm of a Wheatstone's bridge. The balancing resistance was a calibrated standard 1.0050 ohm. The resistance of the bridge wire was 0.01032 ohm per cm., and this wire was extended by resistances of 40 and 41 ohms respectively at its ends. At room temperature, 24° C., the bridge balanced with the sliding contact at 68.0 cm., whence

$$R = 1.005\frac{41 + 68 \times 0.01032}{40 + 32 \times 0.01032} = 1.03918 \text{ ohms}$$

is the resistance of the steel wire. The battery terminals joined the two large to the two small resistances since this arrangement gave the largest deflections for a given current through the steel wire.

The galvanometer was calibrated with respect to temperature changes of the steel wire by the following simple method. The bridge was accurately balanced with the galvanometer at zero. A standard of 0.001 ohm resistance was then introduced in series with the steel wire. This caused the galvanometer to deflect 18.72 cm. Since the current through the galvanometer is proportional to the change in the resistance of one arm, if the change is small, we may consider each centimeter deflection as indicating a change $\Delta R = 0.00005345$ ohm in the resistance of the steel wire. Thus if a small change in the resistance of the wire is produced by a temperature change $\Delta\theta$, $\Delta R = R\alpha\Delta\theta$. We carefully determined the temperature coefficient of resistance α for the wire and found $\alpha = 0.002820$ ohm per ohm per degree at 24° C. Thus

$$1 \text{ cm. deflection} = \frac{0.00005345}{1.03918 \times 0.002820} = 0.01825° \text{ C.}$$

change in the temperature of the wire. There remains the problem of determining the deflection of the galvanometer, following a given change in the tension of the wire, which would occur if the galvanometer could respond *instantly* to temperature changes.

In order to reduce the rate of loss of heat from the wire it was passed axially through a polished tin tube whose ends were loosely plugged with cotton and which was covered with a thick layer of cotton to protect it from the effect of slight temperature variations in the room. This reduced the rate of loss of heat to less than half the rate when freely exposed.

After stretching the wire several times to avoid the anomalous effects of the first stretch the experiment was conducted as follows. The bridge was carefully balanced while the wire was kept taut by the constant tension of 2.5 kg. Then the galvanometer key was opened and the stretching weight added to the end of the wire. After standing several minutes the stretching weight was suddenly released by a snap and simultaneously the galvanometer circuit was closed and the deflections at five-second intervals were recorded. After the initial outward swing the galvanometer moved slowly back to zero as the wire cooled to room temperature. These readings were repeated five times each for changes of 5, 10 and 15 kg. respectively in the stretching force. The table of observations with five kg. shows the consistency of the results, especially

Time Sec.	Deflection (Cm.).						Time Sec.	Deflection (Cm.).					
	1	2	3	4	5	Ave.		1	2	3	4	5	Ave.
0	0.00	0.00	0.00	0.00	0.00	0.00	65	0.60	0.60	0.65	0.65	0.60	0.62
5	3.10	2.00	3.20	3.40	2.90	2.92	70	0.50	0.50	0.55	0.55	0.50	0.52
10	3.95	3.65	4.00	4.00	3.70	3.86	75	0.40	0.42	0.45	0.45	0.40	0.43
15	3.80	3.60	3.80	3.80	3.50	3.70	80	0.35	0.37	0.40	0.40	0.30	0.36
20	3.30	3.30	3.30	3.30	3.05	3.25	85	0.30	0.30	0.30	0.35	0.27	0.30
25	2.80	2.80	2.85	2.80	2.70	2.79	90	0.23	0.24	0.23	0.28	0.20	0.23
30	2.40	2.40	2.40	2.40	2.20	2.36	95	0.20	0.20	0.18	0.22	0.17	0.19
35	2.00	2.00	2.00	2.00	1.90	1.98	100	0.15	0.18	0.15	0.20	0.15	0.16
40	1.70	1.60	1.65	1.60	1.50	1.61	110	0.14	0.10	0.10	0.15	0.10	0.13
45	1.30	1.30	1.30	1.35	1.20	1.29	120	0.10	0.08	0.10	0.10	0.05	0.09
50	1.10	1.10	1.10	1.10	1.00	1.08	130	0.05	0.00	0.05	0.05	0.00	0.03
55	0.90	0.90	0.90	0.90	0.85	0.89	140	0.00	0.00	0.00	0.05	0.00	0.01
60	0.75	0.75	0.75	0.80	0.70	0.75	150	0.00	0.00	0.00	0.00	0.00	0.00

after about ten seconds, when any effect of not pressing the galvanometer key exactly with the release of the weight becomes negligible. The logarithms of these averages, and also those for 10 and 15 kg., are plotted with the time in the accompanying figure.

The first deflections depend upon the moment of inertia and damping factor of the galvanometer as well as upon the rise in temperature of the wire. But after about thirty seconds the deflection at any instant accurately records the temperature of the wire at that instant, as is shown by the following analysis. Thus the curves after thirty seconds represent the cooling curves of the wire following these three changes in tension, and the points a, b, c at which these curves, extended, intersect the axis $t = 0$ give the deflections which would be recorded if the galvanometer could reach a steady deflection before the wire loses part of the heat developed.

The validity of this statement is proved by the solution of the equation of motion of the galvanometer,

$$I\frac{d^2x}{dt^2} + D\frac{dx}{dt} + Mx = ifM,$$

where x is the deflection, I is the moment of inertia and f the sensitiveness of the galvanometer, D is the moment of damping at unit rate of deflection, M is the moment of restoring force due to the suspension and i is the current through the galvanometer. The current at any instant t is given in terms of the initial rise in temperature θ_0, the resistance R of the wire and its temperature coefficient of resistance α and a constant k depending on the other resistances and the electromotive force in the bridge by

$$i = kR\alpha\theta_0 e^{-\frac{\sigma}{ms}t},$$

where σ is the thermal coefficient of surface conductivity of the wire and ms is its heat capacity per unit length. Putting

$$\frac{D}{I} = A, \qquad \frac{\sigma}{ms} = c,$$

$$\frac{M}{I} = B, \qquad \frac{2}{A - \sqrt{A^2 - 4B}} = T_1,$$

$$\frac{fMkR\alpha}{I} = C, \qquad \frac{2}{A + \sqrt{A^2 - 4B}} = T_2,$$

the equation reduces to

$$\frac{d^2x}{dt^2} + A\frac{dx}{dt} + Bx = C\theta_0 e^{-ct}, \tag{1}$$

of which the solution is

$$x = \frac{C}{C^2 - 2AC + 4B}\theta_0 e^{-ct} + c'e^{-\frac{t}{T_1}} + c''e^{-\frac{t}{T_2}},$$

where c' and c'' are the constants of integration.

The time constants T_1 and T_2 may be determined from the case where the right member of equation (1) is zero. To do this a portion of the bridge wire was short-circuited so that the galvanometer maintained a steady deflection at 7.5 cm. The short-circuiting key was suddenly removed and the readings noted at short intervals as the galvanometer returned to zero. The results are shown in the figure by the curve ag whose equation is

$$x = c_1 e^{-\frac{t}{T_1}} + c_2 e^{-\frac{t}{T_2}}.$$

T_1 is evidently too small to be detected (showing that the damping moment is very large compared with the restoring moment due to the suspension). It is certainly less than 0.5 second so that this component of the curve may be neglected. T_2 is the time taken for x to fall to $\frac{7.5}{e}$, and is about 5.5 seconds. It is seen from the curve that the effect of this term is certainly negligible after 30 seconds.

Beyond thirty seconds, therefore, the deflection is given by

$$x = \frac{C}{C^2 - 2AC + 4B}\theta_0 e^{-ct} = x_0 e^{-ct}.$$

Thus the curves beyond 30 seconds represent the true cooling curves and the points a, b, c, at which these straight lines intersect the axis $t = 0$, are the true values of the initial deflections which would have been observed if the galvanometer had responded instantly to the initial currents.

The most probable straight line through the points beyond 30 seconds was determined in each of the three cases by the method of least squares and the probable error calculated. The three initial deflections a, b and c were thus found to be 7.5 ± 0.037 cm., 15.0 ± 0.047 cm. and 22.5 ± 0.056 cm. respectively. When these deflections are multiplied by the calibration constant 0.01825 we find that temperature changes of 0.1369° C., 0.2737° C. and 0.4106° C. were produced in the wire by changes of 5, 10 and 15 kg. respectively in the stretching force.

Comparison of Experiment with Theory.—In order to take into account possible variations in the thermal coefficient of linear expansion of the wire due to tension, we measured the coefficient of expansion between temperatures of 13.6° C. and 32.2° C. under tensions of 4.5, 7.0 and 9.5 kg., which were the average tensions in the three cases. The wire was passed axially through a cylindrical water jacket and the expansion was measured by micrometer microscopes. These results, together with the other constants of the wire are given in the following table:

Radius of wire	$r = 0.0310$ cm.
Density of wire	$\rho = 7.930$
Coefficient of linear expansion (4.5 kg.)	$a = 0.00001109$
(7.0 kg.)	$a = 0.00001111$
(9.5 kg.)	$a = 0.00001115$
Specific heat of wire	$s = 0.1178$
Room temperature	$\theta = 297.0°$ K.
Mechanical equivalent of heat	$J = 4.185\ (10)^7$
Acceleration of gravity	$g = 980.6$

The values of $\Delta\theta$ calculated from Thomson's formula by substitution

of these quantities are given in the following table and compared with the experimental results. The theory is verified much more closely and consistently than heretofore. If the mean of the experimental

F(kg.).	$\Delta\theta$ °C. (Calculated).	$\Delta\theta$ °C. (Observed).	Discrepancy, Per Cent.	Probable Error, Per Cent.
− 5.0	0.1366	0.1369	−0.22	±0.50
−10.0	0.2738	0.2737	+0.04	±0.32
−15.0	0.4122	0.4106	+0.39	±0.25
			Ave. = 0.07	

results is used to calculate the mechanical equivalent of heat we find $J = 4.188\ (10)^7$ ergs per calorie. The best results for steel previously obtained (by Haga) lead to the value $J = 4.290\ (10)^7$ ergs per calorie, in which the error is about thirty-five times that in the present work.

PHYSICAL LABORATORY,
REED COLLEGE.

THE ELECTRICAL, THE PHOTO-ELECTRICAL AND THE ELECTRO-MECHANICAL PROPERTIES OF CERTAIN CRYSTALS OF METALLIC SELENIUM, WITH CERTAIN APPLICATIONS TO CRYSTAL STRUCTURE.

BY F. C. BROWN.

OUR information concerning the structure of the atom has perhaps advanced faster of recent years than has our information about the larger unit which is composed of atoms. The phenomena of radioactivity which are fundamentally independent of crystal structure have in a large measure furnished the data for studies on the atom. In the end the facts about either unit will aid in the understanding of the other unit of matter. Bragg's studies[1] on the reflection of X-rays show the crystal structure to be made up of stationary parts. These parts indicate charges of electricity resting almost in a plane. I wish in this paper to correlate some notions about the atom and the crystal after I have related some experiments with crystals of metallic selenium which point toward a new departure as to the rôle of the conducting electron in matter. These crystals of selenium show many unique properties involving co-related phenomena of electrical, optical and mechanical nature, and it is because of these new phenomena that we have a possible opportunity of arriving at further advances in the electrical view of matter. There will be given reasons however for believing that these related phenomena are merely accentuated in selenium much as the magnetic properties are accentuated in iron.

ACTION AT A DISTANCE BY LIGHT.

Recently[2] it was shown that when light illuminated one part of a crystal that there was a consequent change of electrical conductivity throughout the crystal. The electrical effect was observed in one case 10 mm. away from the point of illumination, and the effect was apparently as large as if the illumination fell on a point only 0.5 mm. away. In the latter paper referred to it was shown that this electrical effect could even be transmitted from one crystal to another when the crystals

[1] W. L. Bragg, Proc. Roy. Soc., *A*, 89, p. 248, and W. H. Bragg, Proc. Roy. Soc., *A*, 89, p. 277, 1914.

[2] Phil. Mag., Ser. VI, vol. 28, p. 497, and PHYS. REV., N. S., vol. 4, pp. 85 and 507, 1914.

were grown together. The essential difference between the direct action and the transmitted action as thus far observed is that the maximum effect for a given energy intensity is produced at longer wavelengths in the latter case. This shifting of the maximum sensibility was observed for 30-second exposures, which duration probably gave very nearly the equilibrium effect for a given intensity.

The action was, so far as could be observed, just as rapid when transmitted to a distance of 10 mm. as when transmitted only 0.5 mm. It thus can not be a mere temperature disturbance. Furthermore the major portion of the recovery after removing the light source was almost instantaneous.

When the crystal examined was illuminated at various points by a narrow beam of light it appeared that the light action was not uniform along the crystal. There were centers of varying sensibility. Thus the crystal has a mechanism of rather large dimensions, which when acted upon at different places produce results differing in magnitude.

The question that first arises is whether the equilibrium conductivity with a given illumination on a crystal represents an altered state of the crystal structure or whether it represents merely a condition in the crystal in which there is a constant liberation and supply of electrons that scatter throughout the crystal; the supposition being that for equilibrium the balance is kept up by the absorption of a similar quantity of electrons.

THE PRESSURE EFFECT IS NOT TRANSMITTED.

It has already been shown[1] that the conductivity of either the acicular or lamellar crystals may be increased several hundred times by the application of mechanical pressure. Also it was demonstrated in the same paper that the absolute change of conductivity by a given intensity of illumination increased proportional to the conductivity in the dark. Apparently the increased pressure on the crystal made it easier for the light to free the electrons. The view that is here being taken is that the greater the pressure the greater is the number of electrons existing in a state of equilibrium almost unstable. When in the dark it is these semi-fixed electrons that are transferred from center to center by electrical potential differences and it is also these that light acts upon and makes free of the atomic structure. Consequently the greater the number of these semi-stable electrons the greater will be the change of conductivity by a given illumination. This is a fairly simple explanation of the increased light-sensitiveness of the crystals when under high pressures. Of course later information may make this explanation purely a conventional one.

[1] PHYS. REV., Ser. 2, Vol. 4, p. 85, 1914.

The above view was formulated to accord with the experimental result showing the pressure effect not to be transmitted to parts of the crystal not under pressure. The experiments were carried out as shown diagramatically in Fig. 1. The opposite ends, marked (1) and (2), of either a lamellar or an acicular crystal were placed between separate electrodes of brass. This apparatus permitted a number of experiments of varying character to be performed. If end (2) were illuminated the conductivity at end (1) changed almost as much as it did at the illuminated end. If the pressure were increased on end (2) the absolute sensibility to light increased almost proportional to the pressure, but the change of conductivity at (1) by illumination at (2) was not increased by this increase of pressure on end (2). However if the pressure were applied at (1) instead of (2), and the illumination just as above on end (1), then there was an increase in the absolute conductivity at (1).

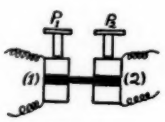

Fig. 1.

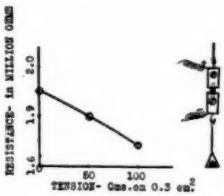

Fig. 2.

The conclusion is that the *pressure effect merely makes it easier for the light to change the conductivity and that the pressure does not act except at the point of application.* As will be pointed out elsewhere these results lead directly to the conclusion that pressure does not increase the conductivity by adding free electrons. And in view of the fact that the increased light-sensitivity due to high pressure is not transmitted we are justified in concluding that light does not produce free electrons in the generally accepted sense. In other words none of the conductivity in these crystals can arise from free electrons such as exist in metals according to the hypothesis of Richardson and Brown.

In the above experiment it was immaterial whether or not a current was flowing across both ends of the crystal simultaneously. A second set of experiments was made, with the same apparatus in such a way that the current flowed all the time through the part of the crystal under study and this same part of the crystal was not under pressure by the electrodes.

The pressure was applied simultaneously on both ends of the crystal. The essential part of the resistance was between the electrodes and this part of the crystal was obviously not under pressure. By varying the

pressure on the crystal there was no change in the resistance. The electrodes were separated in different tests by distances ranging from 0.5 to 5 mm. In no case was there evidence that the change of resistance by pressure extended beyond the region under stress. Likewise the light-sensitiveness of the middle portion of the crystal did not increase as a result of the pressure on the ends.

Another related electro-mechanical effect is the change of resistance accompanying a stretching force. For the study of this effect five branch crystals growing out from a central spine such as reproduced in the earlier article were chosen. The opposite ends of these crystals were clamped in brass electrodes as shown in Fig. 2, so that the stress was distributed among the five crystals. The crystals were stretched by adding weights to a pan pulling on one of the electrodes as shown. This experiment was rather difficult because the apparent malleability of the crystals caused them to flatten out, tear and pull out of the clamps and also because the slightest twisting would cause the crystals to weaken and break. However I did succeed in observing that the crystals would withstand a stretching force greater than 10 kgm. per square centimeter. With such stresses there was a decided decrease of resistance as shown in the curve of Fig. 2. When the weights were removed the resistance usually increased again to its previous higher value without stress, thus indicating the crystal to be in equilibrium either with or without the additional forces.

The change of resistance for tensile forces does not seem to be as great as for compression forces as previously related. The interpretation that is to be placed on these results is that stress by stretching brings an increased number of electrons into almost unstable equilibrium and thus increases the current with a given potential difference. The fact that the effect is not so large as by compression forces may arise from an increasing of the distance between some of the semi-stable electrons, when this distance is measured in the direction of current flow.

THE ELECTRICAL CONDUCTIVITY WITH VARYING ELECTRICAL STRESSES.

On the preceding view of the structure of the crystal in which conducting charges are tied up in the atom in a quasi-stable condition, we should expect the number of electrons that could be dragged out of their fixed positions would vary with the electrical forces acting on them, and that only forces acting in the direction of current flow would alter the magnitude of the current. In what way the current should vary with the electrical forces will depend upon a more exact picture than we are yet able to formulate. When a lamellar crystal was under pressures only

slightly greater than atmospheric, the resistance varied with increasing potential difference at the electrodes as shown in the lower curve of Fig. 3. The potential was applied in the direction of the current flow for about 20 seconds. For low potentials the change of resistance was almost steady after this time, but for high potentials, above 100 volts, there were signs of unsteadiness if the current were left on too long. Next the pressure was increased so that the conductivity increased twenty times in the dark, and the resistance was then observed to vary as shown by the upper curve in Fig. 3. At first sight one might be inclined to say that the change of resistance with varying electro-motive force is materially less with high pressure on the crystal. But inspection shows that only the percentage change is greater with low pressure. The following table gives the conductivity for some potential differences as deduced from the data graphed in Fig. 3.

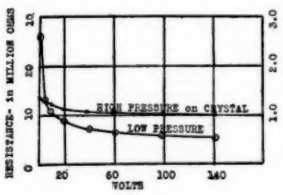

Fig. 3.

Difference of Potential.	Conductivity in Dark.	
	With Low Pressure.	With High Pressure.
1.4 volts	3.84×10^{-8}	75.2×10^{-8}
10 volts	9.17×10^{-8}	83.3×10^{-8}
41 volts	14.3×10^{-8}	96.1×10^{-8}
100 volts	18.2×10^{-8}	98.0×10^{-8}
143 volts	19.6×10^{-8}	100×10^{-8}
Extreme variation in absolute specific conductivity	16×10^{-8}	$?5\times10^{-8}$

It is observed that the extreme variation of conductivity for the potentials used was somewhat greater with the crystal under high pressure than under low pressure. This merely signifies that the saturation current was not nearly reached by increasing the conductivity by a factor of twenty. The increased pressure probably makes the electrons free to leave the atomic structure with lower potentials. The instability of the electrons is increased by either mechanical pressure or electrical stresses.

Light-sensitiveness with Different Potentials.—If light produces free electrons and the electrical stress merely pulls electrons out of the atomic structures in the line of conduction, we should expect that the conductivity by illumination would be increased by the same amount regardless of the potentials across the crystal. This is on the supposition that the conductivity increases proportional to the increase in the

number of conducting electrons, and that the stability of the fixed electrons in no wise determines how many are to be freed by light.

The following table gives the results that were obtained to check the validity of the above, when the crystal was illuminated with light of constant intensity until equilibrium was reached.

Potential Fall Across Crystal.	Resistance.		Ratio of $\frac{C \text{ in Dark}}{C \text{ in Light}}$.
	In Dark.	Illuminated.	
1.4 volts	1.30×10^6	$.82\times10^6$	
	1.20 "	.80 "	
	1.20 "	.79 "	
	1.20 "	.79 "	
	1.20 "		$1.53\pm.03$
60 volts	$.475\times10^6$	$.299\times10^6$	
	.475 "	.310 "	
	.49 "	.323 "	
	.492 "	.325 "	
	.495 "	.330 "	$1.53\pm.02$

It is observed that the percentage increase of conductivity is the same regardless of what the initial conductivity may be as influenced by the potential fall across the crystal. But this means that the absolute increase of conductivity is nearly three times greater with the higher voltage. Therefore the presumptions mentioned above are not true. The exactness of the ratio of the increase of conductivity would favor the view that the light renders a constant number of electrons in a quasi-stable equilibrium, and that the apparent increased sensibility by using higher potentials is merely the result of a pulling out of a greater number of semi-stable electrons.

It should be noted that the constancy of the light-sensibility ratio above shown for electrical potentials is identical to the result noted in my previous paper[1] where the percentage increase of conductivity by illumination remained constant for varying pressures. No doubt the two sets of results have an analogous explanation and this leads to the suggestion that electrical stresses and mechanical pressures alter the equilibrium of the crystal structure in identical ways.

The Non-transmissibility of the Electrical Potential Effect.—If the above identity exists we should expect that the effect of high potentials should alter the conductivity only on that part of the crystal in the immediate field the same as found for the pressure effect. Two experiments were carried out in a fairly satisfactory manner to answer this question.

In the first experiment one end of an acicular crystal was placed

[1] Loc. cit.

between electrodes differing in potential by 1.4 volts. The exterior circuit was closed through a galvanometer as shown in Fig. 4. The deflection of the galvanometer was noted. Then a potential difference of 100 volts was applied across the opposite end (*B*) of the crystal. This high potential changed the conductivity of end (*B*) by about a factor of five, but there could not be detected the slightest change of conductivity at the end *A*, as result of the potential effect, even when the opposite sets of electrodes were approached within one millimeter of each other. It should also be noted that there was no permanent potential generated at (*A*) by the application of the high potential at (*B*). Such a potential would have been indicated by the galvanometer.

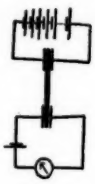

Fig. 4.

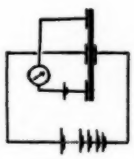

Fig. 5.

The second experiment was designed to detect any effect by an electrical stress acting at right angles to the current flow. The high potential was applied across the middle of the acicular crystal as shown in Fig. 5. The conductivity was being measured by a current flowing lengthwise of the crystal. However a strip of mica on one of the middle electrodes prevented the flow of a current by the high potential of 200 volts.

The result of this experiment was also negative. These two experiments show that a selenium crystal may change its resistance along one axis without altering the resistance along a perpendicular axis. This result is explicable on the view that free electrons are not the current bearers in non-illuminated selenium.

It may be that the piezo-electric effect, as exhibited for example in quartz where a number of electrons are freed by pressure, bears a certain resemblance to the effect described above. The quartz perhaps does not show a corresponding change of resistance because of its extreme insulating properties.

CONCLUSIONS.

It has been shown, (1) when a selenium crystal is illuminated at certain points that the conductivity of the entire crystal is increased, (2) that when pressure is applied to the crystal only that part of the crystal under pressure is altered, (3) that electrical forces alter the conductivity only of that part directly under the forces and further that the influence is exerted only in the direction of the electrical force.

The direct conclusion is that light action has to do with an essentially different mechanism than electrical stresses or mechanical stresses. Starting with the above fundamental facts and correlating the other facts mentioned in the paper, I have attempted to formulate certain notions about the structure of the crystal.

This notion premises that a crystal when in the dark has no free electrons in the ordinary sense such as was found to exist in certain metals by the hypothesis and experimental work of Richardson and Brown.[1] True a crystal conducts electricity when in the dark, but this conductivity is small compared with that of the metals. The elementary notion of the crystal is merely a structure composed of positive and negative charges in equilibrium with each other. But this equilibrium is for a large number of the electrons at least in a very low degree of stability. The electrons would be held in equilibrium by the positive forces essentially, but certain of them while necessary to the complete atomic structure, would nevertheless leave the centers (*i. e.*, perhaps atoms) when under small stresses. So long as an electron remains outside an atom requiring one or more electrons, this electron would behave as the traditional free electron. Thus whatever makes free electrons would increase the conductivity.

The hypothesis is that the conductivity in the dark does not arise from the free electrons, except those that have not had time to adjust themselves following an internal disturbance, but from electrons that are pulled from one atom to the neighboring atom and so on by the electrical forces across the crystal. The following is evidence for this view; first it was noted that for very small electromotive forces the resistance was almost infinite and for increasing potentials up to a certain limit the resistance decreased very rapidly. Secondly, it was noted that very large potential differences acting at right angles to the current flow did not alter the magnitude of the current.

The pressure effect is readily explicable on the basis that no free electrons exist in the crystal when in the dark. Pressure may increase the conductivity many hundred fold, but it will not influence the resistance outside the part of the crystal pressed upon. It would seem then that mechanical pressure merely pushes the electrical charges, associated with neighboring atoms, into a less stable equilibrium, perhaps closer proximity, so that a given electrical stress can pull more electrons from one atom to the next.

We are now in a position to assert something concerning the nature of light-action, based on the fundamental property of transmitted action.

[1] Phil. Mag., Ser. VI, 16, p. 353, 1908.

By some mechanism the light can, no doubt because of its electromagnetic properties, lower the degree of stability of many or all of the electrons throughout the crystal. These same electrons may have their degree of stability yet further lowered by mechanical pressure. The lower the average stability of the electrons the greater will be the current with a given potential difference. With a greater potential difference the same light intensity would therefore seem to produce a greater change of conductivity. The electrons after removal from their fixed positions may behave, until reunited in the structure, somewhat as the traditional electron.

The action of light is not local. The electrons are made less stable or temporarily free by an indirect mechanism operating everywhere in the crystal. The effect is almost uniform at all points. It travels too fast to be a temperature transmission and the maximum sensibility for the transmitted action is in the visible spectrum. The transmission is at least analogous to that of a mechanical vibration, although only certain parts of the crystal may take part in its operation.

The reader will observe that aside from the experimental work the essential new thought in this paper is a new hypothesis to explain the nature of electrical conduction in certain crystals. This hypothesis bears some resemblance to the accepted theory of electrolytic conduction, the distinctive feature being that only electrons move from one center to the next in the chain of centers between electrodes. This view requires that the crystal shall have fixed electrons in its structure but no permanently free electrons.

The Physical Laboratory,
The State University of Iowa.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE SEVENTY-FIFTH MEETING.

A REGULAR meeting of the Physical Society was held in Randall-Morgan Laboratory of the University of Pennsylvania December 29, 1914, to January 1, 1915. It was a joint meeting with Section B of the American Association for the Advancement of Science. Morning and afternoon sessions were held on Tuesday, Wednesday, and Thursday. Vice-President Anthony Zeleny of Section B presided on Tuesday and Wednesday afternoons, and President Merritt at the other four sessions.

On Tuesday afternoon the program consisted of the vice-presidential address before Section B on "Recent Evidence for the Existence of the Nucleus Atom" by A. D. Cole and the presidential address of the American Physical Society on "Luminescence" by Ernest Merritt. On Wednesday afternoon there was a symposium on the Use of Dimensional Equations, led by E. Buckingham, who was followed by A. C. Lunn, A. G. Webster, W. S. Franklin, and others.

The following program of papers was presented:

An A. C. Bridge for the Measurement of the Dielectric Loss and Dielectric Constant at High Voltages and Low Frequencies. CHESTER A. BUTMAN.

Influence of the Concentration of Electrolyte upon Electrode Potentials. ARTHUR W. EWELL.

A New Method of Obtaining a Hysteresis Loop. W. N. FENNINGER.

On Rotation and Magnetization. S. J. BARNETT.

Note on Thermo E.M.F.'s in which the Resultant Peltier Effect is Zero. H. C. BARKER.

Linear Resistance Change with Temperature of Certain Molten Metals. E. F. NORTHRUP.

The Effect of Temperature on the Dielectric Strength, the Dielectric Loss and the Dielectric Constant of Paraffine Oil. CHESTER A. BUTMAN.

A Preliminary Note on the Variation of Stray Power Losses in a Dynamo. W. N. FENNINGER.

Relation Between the Energy of the Cathode Rays and the Frequency of the X-Rays Produced by Them. WILLIAM DUANE.

Thermionic Currents from a Wehnelt Cathode. W. WILSON.

Mobility of Ions at Different Temperature and Constant Gas Density. HENRY A. ERIKSON.

The Radioactive Content of Certain Minnesota Soils. JAMES C. SANDERSON, read by H. A. ERIKSON.

Conducting Gas Layer at a Metallic Surface. G. W. STEWART.

X-Rays From the Electrical Discharge. ELIZABETH R. LAIRD.

X-Rays Produced by Slow-moving Cathode Rays. ELIZABETH R. LAIRD.

Light Due to Recombination of Ions. C. D. CHILD.

Electric Furnace Evidence on the Relation of Spectrum Lines Having Constant Differences in Wave-Number. (By title.) ARTHUR S. KING.

The Mechanical Equivalent of Light. H. E. IVES, W. W. COBLENTZ, and E. F. KINGSBURY.

Fluorescence of the Uranyl Salts under X-Ray Excitation. FRANCES G. WICK.

The Efficiency of Energy Transformation in the Corona Method of Precipitating Fumes. W. W. STRONG.

Leakage of Gases Through Quartz Tubes. (By title.) E. C. MAYER.

A New Method for Measuring Gravity at Sea, with Some Trans-Pacific Observations. LYMAN J. BRIGGS.

The Oxidation of Nitrogen. W. W. STRONG.

The Alleged Dissymmetrical Broadening of the D Lines of Sodium. E. A. ECKHARDT.

Exhibit of Mechanical Models Illustrating (*a*) Subdivision of Alternating Current Between Two Branches in Parallel, (*b*) The Alternating Current Transformer, (*c*) Coupled Circuits in Wireless Telegraphy. W. S. FRANKLIN.

Some Causes of Variation in the Sensitivity of Moving Coil Galvanometers. PAUL E. KLOPSTEG (presented by A. ZELENY).

A New Standard Phone and Phonometer for any Pitch. A. G. WEBSTER.

A New Form of Radiation Pyrometer. (By title.) S. LEROY BROWN.

The Doppler Effect in X-Ray Spectra and Application to the Kinetic Theory of Solids. L. GILCHRIST AND D. A. KEYS.

On Acoustic Impedance, and an Approximate Theory of Conical Horns. A. G. WEBSTER.

Vapors with Positive Specific Heat in Energy Conversion. (By title.) J. E. SIEBEL.

Progress of B-Particles through Matter. A. F. KOVARIK AND L. W. MCKEEHAN.

A Thirty-two Element Harmonic Synthesizer. DAYTON C. MILLER.

The Result of Plotting the Separation of Homologous Pairs against Atomic Numbers instead of Atomic Weights. HERBERT E. IVES AND OTTO STUHLMANN.

Beaded Lightning. W. J. HUMPHREYS.

A Practical Measurement of Colors. H. E. WETHERILL.

Preliminary Note on a Mercury-vapor Tube Oscillator. B. LIEBOWITZ, introduced by M. I. PUPIN.

On Tuesday evening a public lecture, complimentary to the citizens of Philadelphia and illustrated by experiments and the lantern, was given by

Dayton C. Miller. On Wednesday evening a successful dinner for Physicists was arranged by Professor H. C. Richards at a hotel near the University. This was enjoyed by about seventy members. The members of the Society were the guests of the University of Pennsylvania at lunch each day of the meeting. The registration of the meeting was one hundred and seventeen. The attendance at the various sessions was exceptionally uniform and varied between one hundred and one hundred and fifty.

The result of the mail ballot for officers for 1915 was announced at the meeting as follows: For President Ernest Merritt, vice-president K. E. Guthe, secretary A. D. Cole, treasurer J. S. Ames; for members of Council (three years) C. E. Mendenhall and G. W. Stewart, and for Editorial Board J. S. Ames, A. A. Michelson and E. Buckingham. The reports of the managing editor of the PHYSICAL REVIEW was presented by the editor. It was approved and that of the treasurer reported in the hands of the President, duly audited. Both were ordered printed, to be sent to each member with the announcement of next meeting.

A. D. COLE,
Secretary.

A METHOD OF DETERMINING WHETHER OR NOT THE VELOCITY OF LIGHT DEPENDS UPON THE VELOCITY OF THE SOURCE, BY THE USE OF CANAL RAYS.[1]

BY GORDON S. FULCHER.

LET a source of light, a canal ray for instance, move toward an observer, that is a spectrograph, with a speed v with reference to a system in which the speed of light is c, while the observer is moving toward the source with a speed u with reference to the same system so that the relative speed is $v + u = V$. If the source s and observer o are at a distance apart equal to l at the instant $t = 0$, the 1st and the $(n+1)$th waves will reach the observer at instants $l/(c + u)$ and $1 + (l - u - v)/(c + u)$, if the source sends out n waves per second. The observer receives n waves in the time

$$1 + \frac{l - u - v}{c + u} - \frac{l}{c + u} = \frac{c - v}{c + u}$$

or at the rate of $n[(c + u)/(c - v)] = n'$, per second. The resulting doppler effect would be

$$n' - n = n\frac{v + u}{c - v} = n\frac{V}{c - V + u}.$$

Now suppose the apparatus rotated through 180° so that the relative speed of the source with reference to the observer is the same as before, but the speed with reference to the fixed system is greater. The number of waves received per second by the observer now is

$$n'' = n\left(\frac{c - u}{c - v}\right);$$

[1] Abstract of a paper presented at the Chicago meeting of the Physical Society, November 28, 1914.

the doppler effect would be

$$n'' - n = n\left(\frac{uv -,}{c - v}\right) = n\frac{V}{c - V - u}.$$

Supposing the two spectrograms are taken one immediately above the other the shift in the doppler effect which should be observed if, as we have assumed, the velocity of light in the fixed medium is independent of the velocity of the source, is

$$n'' - n' = n \cdot \frac{2uV}{(c - V)^2 - u^2};$$

or, approximately,

$$\Delta\lambda = \frac{\lambda_1^2}{\lambda} \cdot \frac{2uV}{(c - V)^2} = \lambda \cdot \frac{2uV}{c^2}.$$

If $u/c = 10^{-4}$ (earth); $V/c = 10^{-2}$ (fastest canal rays); $\lambda = 4861$ Å (H_β); then $\Delta\lambda = 2 \times 10^{-6}\,\lambda = .0097$ Å. To measure this, we should require very homogeneous, parallel, canal rays whose high speed must be maintained constant within one part in 10,000 during the experiment. While the experimental difficulties would be very great, they do not seem insurmountable.

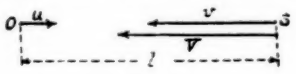

Fig. 1.

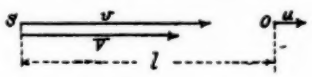

Fig. 2.

It is to be noted that the shift is a first order change of the doppler effect and can not be accounted for, if it is found by experiment to exist, by any second order change of V or l. The wave-lengths are measured in all cases by a spectrometer moving with the same speed with reference to the fixed system.

UNIVERSITY OF WISCONSIN,

NOTE ON THERMO E.M.F.'S IN WHICH THE RESULTANT PELTIER E.M.F. IS ZERO.[1]

BY H. C. BARKER.

TAIT and others have noted that couples having two or more neutral points would give thermoelectric currents maintained by the Thomson effect alone, if the junctions were at the temperatures of the neutral points.

In this case the resultant Peltier E.M.F. is zero as the component Peltier E.M.F.'s are each equal to zero.

The writer has been led to question whether it is generally recognized that the Thomson thermodynamic theory leads to the conclusion that large thermo E.M.F.'s in which the resultant Peltier E.M.F. is zero, are obtainable with couples for which there exists only one neutral point.

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society, December 29–31, 1914.

The condition is easily shown to be that the sum of the junction temperatures be equal to the neutral temperature. The Peltier E.M.F.'s are then equal, and their difference, the resultant Peltier E.M.F., is zero. Thus the current may be said to be maintained by the Thomson effect alone.

It is plain that two temperatures meeting this condition may be so chosen that the thermo E.M.F. is relatively large.

The appended curves exhibit the essential relations.

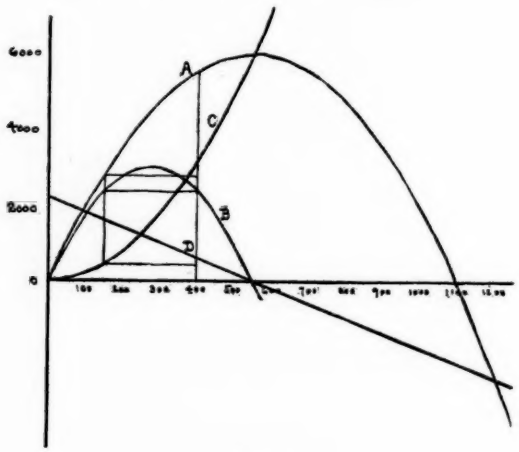

Fig. 1.

Abscissæ represent absolute temperature. Ordinates for curves A, B and C represent E.M.F. in microvolts. Ordinates for Curve D represent microvolts per degree, $\times$ 100.

Curve A. $E = 22\theta - .02\theta^2$. Thermo E.M.F. is given by difference in ordinates.

Curve B. $e_p = \theta \dfrac{\partial E}{\partial \theta} = 22\theta - .04\theta^2$. Resultant Peltier E.M.F. given by difference in ordinates.

Curve C. $e_T = -\int_0^\theta \theta \dfrac{\partial^2 E}{\partial \theta^2} d\theta = .02\theta^2$. Resultant Thomson E.M.F. given by difference in ordinates.

Curve D. $P = \dfrac{\partial E}{\partial \theta} = 22 - .04\theta$. Thermoelectric power.

UNIVERSITY OF PENNSYLVANIA,
PHILADELPHIA, PA.

LINEAR RESISTANCE CHANGE WITH TEMPERATURE OF CERTAIN MOLTEN METALS.[1]

BY EDWIN F. NORTHRUP.

COPPER and tin have been studied to 1680° C., lead to over 1600° C., gold to 1500° C., silver to 1340° C., bismuth to 750° C. and their change of resistance with temperature when molten has been found, within the limits

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society, December 29–31, 1914.

of accuracy of the measurements, to be linear. Lead and tin, particularly the latter, are shown to constitute excellent thermometric materials for the accurate measurement of high temperatures which may be read with apparatus that reads on a uniformly spaced scale directly in degrees centigrade. Several features and relations of interest respecting the resistivities of the above metals are pointed out.

PALMER PHYSICAL LABORATORY,
PRINCETON, N. J.

INFLUENCE OF CONCENTRATION OF ELECTROLYTE UPON ELECTRODE POTENTIALS.[1]

BY ARTHUR W. EWELL.

ACCORDING to Nernst's formula, the potential of an electrode dipping into an electrolyte increases as the concentration of the electrolyte is increased. At ordinary temperatures the amount of increase is $.058/N \log c_2/c_1$ where N is the valency and c_2/c_1 is the ratio of the concentrations. This law has often been closely verified by well-known electrochemical methods, both when the electrode dips in the electrolyte and when the two are separated by ionized air.

A year ago Borelius showed that when single electrode potentials were studied electrostatically the potential decreased as the concentration was increased, the rate of decrease being approximately equal to the rate of increase hitherto observed.

The writer has studied the influence of concentration, employing a modification of the apparatus recently used for determining absolute single potentials.[2] The two electrolytes of different concentrations were contained in two similar glass flasks. The silver film on the outside of each was connected to a pair of quadrants of a Dolezalek electrometer and the deflections of the latter were observed when earthed electrodes were dipped into the electrolytes. The observations gave values for the numerical factor (.058 in Nernst's equation) between .037 and .053 and all negative, thus confirming Borelius's results with a type of apparatus which, unlike Borelius's apparatus, gave absolute potentials independent of Volta effects.

WORCESTER POLYTECHNIC INSTITUTE.

THE ALLEGED DISSYMMETRICAL BROADENING OF THE D LINES OF SODIUM.[1]

BY E. A. ECKHARDT.

H. KAYSER in his Handbuch der Spectroscopie[3] refers to the dissymmetrical broadening of the D lines in an emission spectrum. Bro-

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society, December 29–31, 1914.

[2] This Journal, Vol. IV, No. 6, p. 547.

[3] H. Kayser, Handbuch der Spectroscopie, Vol. II, p. 365.

therus[1] and Iwanow[2] as well as others appear to have subsequently observed the same phenomenon. The present investigation had for its program first the reproduction of this dissymmetrical broadening and then by measurably controlling the factors which are responsible for the broadening to find if possible in what manner the dissymmetry is introduced.

Since the dissymmetries seem always to have been observed in emission spectra it seemed pertinent to investigate whether they exist also in the corresponding absorption spectra. Consequently the light of an arc lamp was made to pass through a strongly absorbing sodium flame and was then focused on the slit of a grating spectroscope. The absorption of the sodium flame was under control within very wide limits. The spectrum was photographed and the distribution of intensity across the spectrum lines was determined by means of a Hartmann photometer.

Although the D lines were broadened much more than they had been in the experiments of Brotherus and Iwanow no dissymmetries of any kind were discovered. The results of the present work indicate strongly that there are no dissymmetries in the absorption spectrum obtained under conditions which are comparable to those in which the dissymmetry has actually been observed in the emission spectrum. If the dissymmetries really exist in the emission spectrum, they appear to have no counterpart in the corresponding absorption spectrum. The work could not be completed because the Hartmann photometer which had been borrowed ceased to be available. It is hoped that the original program may be carried to its conclusion in the near future.

UNIVERSITY OF PENNSYLVANIA,
PHILADELPHIA.

IONIZATION AT METALLIC SURFACES.[1]

BY G. W. STEWART.

WE have much evidence that suggests ionized layers of gas at metallic surfaces at atmospheric pressures, but only the experiments of Anderson and Anderson and Morrison furnish direct evidence.

The apparatus consisted of two polished surfaces, one silver and one german silver, .35 cm. and .50 cm. in diameter respectively. These are plane to within one half wave-length of light. They are approached by an interferometer carriage. Distances were measured by electrical capacity method and by the screw of instrument.

The experiments argue in favor of an ionized layer of gas because of the following points:

1. The minimum distance of approach without apparent conduction was four wave-lengths. Without an ionized layer this distance would have been one wave-length.

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society, December 29–31, 1914.

[1] Hj. V. Brotherus, Ann. d. Phys., Ser. 4, 38, 1912, p. 416.

[2] K. Iwanow, Phys. Z., XIII, 1912, p. 1118.

2. With air, oxygen and hydrogen, the presence of water vapor extends the layer ten to forty wave-lengths.

3. Effect of the three gases named and carbon dioxide is similar, but probably not the same. The influence of water vapor in the case of the latter is less distinct and may not exist at all.

4. Current-voltage curves taken of necessity without the existence of steady states, indicate either ionization by collision or the dragging of additional ions from near the surface by the increased voltage.

5. An approximate value of the contact potential difference is obtained by virtue of the ionized layer.

6. The current-voltage curves shift with direction of field in accord with the contact potential difference value.

The surface layer is found in both of the metals used. Moreover, this layer explains well-known facts with insulators. The origin of the ionization is not clear. It is improbable that it is due to the electrons from within or to a radioactive impurity now known. More probable causes would be the intrinsic radiation of the metal, an unknown radioactive impurity, and chemical action.

The presence of ionized layers of gas is important in the study of coherer action, carbon transmitter action, double layer electrification at low pressures, and the ionization supposed to be due to a penetrating radiation.

THE STATE UNIVERSITY OF IOWA,
IOWA CITY, IA.

LIGHT PRODUCED BY RECOMBINATION OF IONS.[1]

BY C. D. CHILD.

CERTAIN phenomena connected with the luminosity of the light rising from the mercury arc indicate that this light is produced by the recombination of ions.[2] If this explanation is correct, the light must continue for a time after the current through the arc has been stopped. This can be tested by observing the light from an alternating current arc at different phases of the current. Such observations have already been made for the carbon arc in air by Fleming and Petavel[3] who found that the light from the gas between the carbons does not disappear entirely at the time when the current is zero.

Since the phenomena with the carbon arc in air is complicated by the oxidation of the carbon and by the high temperature of the gas, it seemed desirable to repeat their experiment substituting mercury terminals in a vacuum for carbon terminals in the air. This has been done and it has been found that in this case also the light continues to exist for an appreciable length of time after the current has ceased flowing. Such light can not be due to ionization and is in all probability due to recombination of the ions.

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society. December 29–31, 1914.

[2] Phil. Mag. (6), 26, 906, 1914.

[3] Phil. Mag. (5), 41, 339, 1896.

Measurements are now being made for the purpose of learning the length of time that the light continues after the current ceases and the rate at which the light dies away.

COLGATE UNIVERSITY,
HAMILTON, N. Y.

A NEW METHOD FOR MEASURING GRAVITY AT SEA, WITH SOME TRANS-PACIFIC OBSERVATIONS.[1]

BY LYMAN J. BRIGGS.

THE apparatus used was in principle similar to a closed barometer. The air-chamber consisted of a closed glass tube 3 cm. in diameter and 60 cm. long. A capillary tube was sealed into the upper end of the air-chamber and extended nearly to the bottom of the latter,the lower end opening beneath a mercury surface. The capillary above the air-chamber was bent into a zigzag glass spring and ended in a spherical bulb 3 cm. in diameter. This bulb contained a fixed ground glass point extending to the center of the bulb with its axis forming an extension of the axis of the air-chamber. The bulb was mounted in a light carriage sliding on rods clamped to the air-chamber. A micrometer-screw mounted on the rods above the carriage controlled the position of the carriage and bulb. The bulb was highly evacuated and sealed off. The whole apparatus was then packed in crushed natural ice, and the air-pressure in the chamber adjusted until the mercury stood in contact with the glass point. The air-chamber was then sealed off.

As long as the apparatus is vertical and is surrounded by and in equilibrium with pure melting ice, a change in the height of the column is theoretically dependent only on a change in the force of gravity, provided the apparatus is assumed to be free from volume-changes due to external pressure. The height of the bulb is so adjusted by means of the screw that at the time the final reading is made the mercury surface is barely in contact with the glass point. Under these conditions the quantity of mercury remaining in the air-chamber is always the same. The apparatus is, therefore, of the constant-volume type, and the height of the mercury column at two stations is inversely proportional to the force of gravity.

The length of the column is such that when the apparatus is removed from the ice tank, the upper bulb becomes completely filled with mercury. The apparatus may then be tipped in any position and is perfectly transportable. On board ship, the cork-covered ice tank containing the apparatus was swung from gimbals, the latter being suspended from spiral springs.

In the laboratory, a series of readings made on different days agreed to within less than 1 part in 200,000. On board ship, however, things happen that the writer at least did not anticipate, and which combine to reduce the accuracy to 1 part in 50,000, or even less, depending on the weather and the ship. The

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society, December 29–31, 1914.

apparatus is now being modified with the hope of increasing the accuracy of measurements at sea.

U. S. BUREAU OF PLANT INDUSTRY,
WASHINGTON, D. C.

LEAKAGE OF GASES THROUGH QUARTZ TUBES.[1]

BY E. C. MAYER.

A CYLINDRICAL tube of quartz closed at one end of approximately 51 cu. cm. volume and 111 sq. cm. internal superficial area, was found to be pervious to hydrogen at temperatures ranging from 330° C. to 710° C., and at pressures varying from 20 cm. below to 20 cm. above atmospheric pressure. The quartz was of the transparent variety. The curve indicates the general character of the results. Time in minutes is plotted as abscissas, and lengths proportional to volume of gas reduced to 15° C. and 76 cm. pressure as ordinates. Each unit of the ordinate scale corresponds to a volume of 0.217 cu. cm. In the case of oxygen and nitrogen, no leakage could be de-

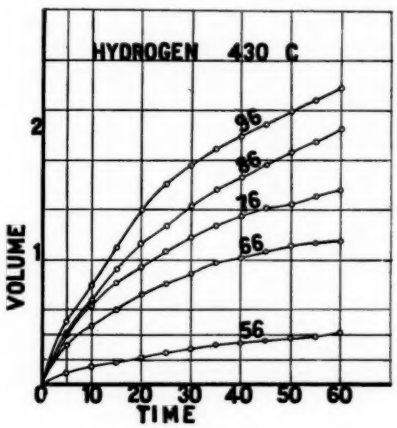

Fig. 1.

tected for pressures less than one atmosphere. Nitrogen did not seem to escape until a temperature of about 430° C. was obtained. At constant temperature the results for all gases showed a considerable increase in leakage with increasing pressures. Under approximately like conditions hydrogen leaks most rapidly and nitrogen least.

Heating was obtained by means of an electric furnace. Temperature was measured by an iron-advance thermocouple.

CORNELL UNIVERSITY,
ITHACA, N. Y.

[1] Abstract of a paper presented at the Philadelphia meeting of the Physical Society, December 29–31, 1914.

NEW BOOKS.

Chemistry. By GEORGES DARZENS. New York: Doubleday, Page and Company, 1914. Pp. viii+122.

Mechanics. By C. E. GUILLAUME. New York: Doubleday, Page and Company, 1914. Pp. xiii+199.

These two volumes belong to "The Threshold of Science" series which, as is well known, met with immediate success in France where it was first published. If one may form an opinion of the whole series from the two volumes before us its success on this continent will be equally great. The monographs "Chemistry" and "Mechanics" are written in a most attractive style by men of eminence. They have been brought out to meet (1) the need of the man who would teach himself the elements of chemistry and mechanics and (2) the need of young people who are showing themselves increasingly eager to acquire a knowledge of the principles underlying these and other branches of science. The books are well illustrated and are issued at the cheapest possible price.

J. C. M.

Die Polhöhenschwankungen. By DR. E. PRZYBYLLOK. Braunschweig: Vieweg and Sohn, 1914. Pp. 1+41. Price, 1.60 Mk.

The "Sammlung Vieweg" of which the present volume forms the eleventh number has the aim to present in concise form a discussion of scientific problems which, at the present, cannot be considered as having been solved satisfactorily. These volumes are of moderate size, contain references to the more important publications on the subject and thus greatly facilitate a general orientation in a given field. The book here reviewed is a characteristic example.

Increased accuracy of astronomical observations has proven the existence of periodic variation of latitude, or, a shifting of the earth's pole. This was suspected by Bessel as early as 1844 and clearly shown to be the case by Chandler forty years later. In 1889 the solution of the problem was undertaken by the International Geodetic Association and since then continuous, systematic observations have been made in a number of suitably located observatories. But the causes for the now fully recognized and accurately determined periodic variations of latitude have not yet been satisfactorily explained. Przybyllok gives an interesting account of the historical development of the problem and the results so far obtained.

K. E. G.

Principles of Physics. By W. E. TOWER, C. H. SMITH and C. M. TURTON. Philadelphia: P. Blakiston's Son and Co., 1914. Pp. xi+466.

This is a high school text written by three experienced high-school teachers. Throughout the book the authors have been true to their conviction that—to

quote from the preface—" the most efficient teaching in physics involves a departure from the quantitative, mathematical methods of presentation—toward a method better adapted to the capabilities, interests, and requirements of the young people." In common with other modern high-school texts the discussion of force and motion is given after mechanics of liquids and gases. The chapters on sound and light follow those on electricity and magnetism. The subject matter and its treatment does not differ materially from that found in other books of this kind. The style is simple and clear, applications to common, everyday experiences are frequent and the illustrations faultless.

K. E. G.

Kräfte ünd Spannungen; Das Gravitations- und Strahlenfeld. MAX B. WEINSTEIN. Braunschweig: Vieweg und Sohn, 1914. Pp. vi+64. Price, M2.

This is the eighth of the Vieweg series of pamphlets on pending questions in science, and is designed to give a concise account of modern theories of force, meaning thereby chiefly those which have grown out of Maxwell's theory of surface stresses, and which are closely related to the recent theory of relativity.

Following some introductory remarks on causality, atomistic theories, and a few mathematical definitions, the first half of the book is devoted to Maxwell's original formulas for the electromagnetic stresses, to the analogous four-dimensional theory developed by Minkowski, and to the modifications suggested by Hertz, Abraham, and others; the latter half is devoted to forces in their purely mechanical aspect and to the recent theories of gravitation, which are so intimately related to electromagnetic theory and the principle of relativity. The treatment is summary in form, and emphasis is placed chiefly on the formulation of theories, with only occasional reference to physical interpretation or experimental test.

The subject is both fascinating and perplexing, and such a birds'-eye-view will be interesting to readers who are familiar with vector analysis, electromagnetics, and the Einstein-Minkowski theory, to whom alone it is likely to be fully intelligible. Though published independently, the book may be considered a natural supplement to the author's recent volume on the physics of moving matter.

A. C. L.

Experiments. By PHILIP E. EDELMAN. Minneapolis: Edelman, 1914. Pp. 1+256. Price, $1.50.

This book is dedicated to " all who are interested in progress." It contains a large number of experiments in the fields of chemistry, current electricity, wireless telegraphy, horticulture, etc. It closes with about fifty pages of a general discussion on science and invention, and " research." Characteristic topics are such as the building of small motors, transformers, of stations for wireless telegraphy, X-ray experiments, experimental aeronautics. Those who wish to play with science will find in the book many practical hints and by its use may be led to a desire for a deeper and broader knowledge of the subjects presented in the book.

K. E. G.

Dynamische und Statistische Gesetzmässigkeit. By MAX PLANCK. Leipzig: J. A. Barth, 1914. Pp. 1+31. Price, 1 M.

The distinguished author of this address, delivered at the celebration in memory of the founder of Berlin University, discusses for a general audience the points of contrast between the applications of the dynamical and the statistical methods in science. He points out that in physics the application of the statistical method is justified by the demonstration of the atomic hypothesis given by the study of the Brownian movements. He calls attention to the possibility of the occurrence of events of which the probability is small, and illustrates his general statements by interesting examples. When considering the necessity of inquiring, whenever a law or regular procedure in nature is demonstrated, whether the law observed has a dynamical or a statistical basis, he asserts that, in the final thought on even the statistical problem, an element of dynamical certainty must enter. The address as a whole is an eloquent and pleasing presentation of a fundamental question in natural philosophy.

W. F. M.

Principles of Electrical Measurements. By ARTHUR WHITMORE SMITH. New York: McGraw-Hill Book Company, 1914. Pp. xiv+233. Price, $2.00 net.

This book is designed for beginners in electrical engineering or for advanced students in physics who wish to master the details of electrical measurements. The book is self-contained in that, before any set of experiments is described, the elementary facts, the definitions and laws are presented which are necessary to an understanding of the experiments. There is not the same preparation made for the understanding of the instruments which are used in the experiments. They are apparently to be taken on faith. All the usual problems of electrical measurements are adequately discussed. The treatment of magnetism is particularly developed. It appears that the subject is one which has been of special interest to the author.

W. F. M.

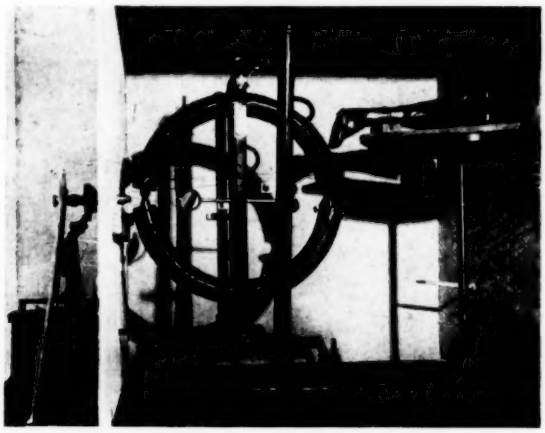

Fig. 2.

Measuring a horizontal component. One side of enclosing box removed to show apparatus within.

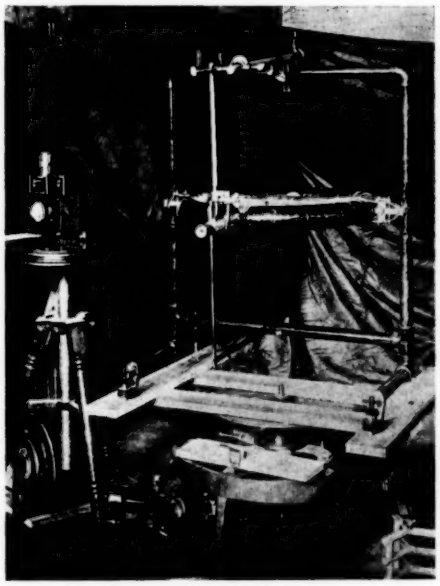

Fig. 4.

Absolute determination of horizontal component of earth's angular velocity.

ARTHUR H. COMPTON.